Industry and academia partnership for aquatic renewable energy development in Colombia: A knowledge-education transfer model from the United Kingdom to Colombia

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Abstract: The need for “industry-academia knowledge transfer (IAKT)” and close collaboration in Colombia has been recognised as critical to innovation, while in the United Kingdom (UK) an IAKT model has been successfully deployed in the UK benefiting both stakeholders. As a result in Colombia, an IAKT model does not exist to guide these two key stakeholder groups. The methodology used is based on the analysis of the data collected directly from the aquatic renewable energy (ARE) industry and academia in the Orkney islands (Scotland). In addition, literature available in the public domain was used and analysed. Having this information, a knowledge-education model is proposed for the Colombian context. The IAKT model curriculum was based on ARE course topics and validated in a preliminary phase with UCC undergraduate engineering students from different disciplines. The results were very promising in terms of the skills developed by the students, not

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PUBLIC INTEREST STATEMENT

The need for industry-academia knowledge transfer (IAKT) has seen an increase in the last years in Colombia along with innovation playing a key role while in the United Kingdom (UK) an IAKT model has been successfully transferred from the industry to the academia in the UK benefitting both stakeholders. In the case of Colombia, such an IAKT model does not exist to guide these two key stakeholders.

This paper proposes an IAKT model based on ARE course topics in Colombia and validated in a preliminary phase with UCC undergraduate engineering students from different disciplines. The results were very promising in terms of the skills developed by the students, not only technical but also in results communication, teamwork, critical thinking and so on.
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Subjects: Engineering Education; Mechanics; Renewable Energy; Energy & Fuels

Keywords: capacity building; knowledge transfer; aquatic renewable energy; sustainable developments goals; industry-academia collaboration

1. Introduction

The dynamism in the use of information and communication technologies (ICT) has accelerated the processes of globalisation and an economy based on the intensive use and development of scientific, technological and economic knowledge, to enhance innovation as a key variable for national growth and development. Innovation in developed countries has become a source of growth in wealth, employment and improvement of per capita income and associated quality of life (Beraza Garmendia & Rodríguez, 2012).

Over the past four decades, knowledge transfer has made a significant contribution to innovation and technology transfer. It is considered as a multidimensional and economic phenomenon taking place in complex, heterogeneous international environments (Mcmullen & Dimov, 2013).

Technology transfer (TT) is correlated with knowledge transfer and both, in turn, support growth in the capacity for innovativeness, invention and innovation (Khadhraoui et al., 2016). Whilst innovativeness measures the degree of cultural predisposition to innovation and the level of novelty of an innovation and its effects on the environment (Dotzel et al., 2013), invention considers a new solution to a techno-economic problem, whereas innovation leads to growth in the economic benefits for organisations (Ahuja et al., 2013). Some authors define innovation as the number of products, processes, programs and services that a company has for development (Abdi & Senin, 2015). Some others define innovation as a different way of doing things in an organisation, whilst others define it as the successful implementation of creative ideas within an organisation (Khadhraoui et al., 2016).

Technology Transfer (TT) theory has developed rapidly with several conceptual models emerging over time. In 1997 Norman Abramson defined it as “the movement of technology and know-how between partners, individuals, entities and companies, with the aim of improving knowledge, innovation abilities and strengthening their competitive position” (González, 2011; Kelly et al., 2006). In essence, TT is considered the socioeconomic movement from a supplier to a receiver of a valuable asset that can include technical means and knowledge, know-how and experience, expressed in tacit or explicit knowledge that usually has an economic value.

One interesting contribution to the TT models is given by Bradley, S.R et al. (Bradley, 2013), who in their model emphasises four nonlinear mechanisms in TT.

- First, the reciprocal relations of the triple helix between university-industry-government.
- Second, the concept of multi-diversity, which can be between, programs of a university or different companies.
- Third, the concept and application of open innovation, the mechanism by which universities acquire and share their intellectual property.
- Fourth, the use of so-called open source, which facilitates the transfer of knowledge among collaborators through the use of technical standards and knowledge exchange (Chesbrough, 2003; Etzkowitz & Leydesdorff, 2000).

In the study by Bozeman et al. (Bozeman et al., 2015), the authors developed ways to assess the effectiveness of the TT process. In their conceptual model, called the Model of Contingent Effectiveness, they suggest some aspects to improve the effectiveness of the TT, which includes...
to take the maximum benefit from what was done outside the door, identify and measure the levels or ranges of the expected impact and promote the greatest development of knowledge of human capital. Their model also considered the identification of the relevant indicators of TT-impact in terms of measurement of the public value of the TT process and its correlation with processes and activities associated with TT between universities, the state and companies. These authors also observed that a large part of the literature on TT focuses on the analysis of international relations and technology of the owner.

Another aspect is that the technological development in developing economies is based on the use of ICT, which, given the need for having a reliable and efficient infrastructure, is no easy task for those countries (Quiroga-Parra et al., 2017). The process warrants an understanding of the elements and characteristics of ICT along with local constraints that depend on each country’s technology transfer and development policies, an aspect that is critical to the transfer of information and technological knowledge (Kahen, 1996). On the other hand, TT involves the movement of routines, practices, use of technologies and human capital, which are adapted and institutionalised in the new environment.

The implementation of TT is affected by the cultural difference between the parties (Nguyen & Aoyama, 2015) where criteria such as attitude, motivation and complexity have a significant influence on the likelihood of success (Claire Erensal & Esra Albayrak, 2008). Similarly, culture affects values, attitudes and behaviours within an organisation and consequently impact the success of TT (Pauleen et al., 2006). Nevertheless, despite considerable advances in studies on the subject and the empirical findings, we still do not have a comprehensive understanding of how to mitigate the potential adverse impact of the “cultural difference” criteria (Nguyen & Aoyama, 2015).

Some of the recent empirical findings point to the critical need for people involved in the TT process to have a clear understanding of the required quality of the product or service. Thus, the quality attribute of the product or service is a central element, without which it becomes difficult to manage the TT process effectively.

The process begins with the commitment of the management in setting objectives, policies and procedures. Teamwork is another relevant variable in the process. In particular, the fundamental elements of TT are based on the leadership vision for learning as a characteristic of the whole organisation that integrates the learning process of individuals, groups and organisations. That is, TT management practices take place in an intercultural environment, are the sum of practices of at least two parties and success is a consequence of the vision, knowledge and capacity of management (Nguyen & Aoyama, 2015).

TT needs a strong commitment of academia which has the responsibility of educating the future professionals according to the actual needs of the society. The need for this has never been greater as today the world faces extraordinarily big challenges as the effects of climate change increase and traditional technoeconomic energy production models need to be re-evaluated and innovated (Alcayaga et al., 2019). As the world demand for electricity is increasing and conventional energy resources are fast depleting, the production of renewable energy-based electricity is the only alternative (Belu & Husanu, 2012). It is necessary to educate for a fast-changing world. In this context, the skill-based models and the education in sustainable, renewable energies are gaining ground (Belu & Husanu, 2012; Kandpal & Broman, 2014; Unigarrow-Gutierrez, 2017). The need for renewable energy education has been recognised worldwide, and during the last decades, several countries have initiated academic programs on renewable energy technologies.

According to Kandpal and Broman (2014), it is important to ensure that the education program covers all renewable energy resources emphasising locally available technologies and resources. It is emphasised the program should incorporate the “whole-lifecycle” study and evaluation of resources, design, manufacture, installation, performance monitoring, troubleshooting and
maintenance. It is also important to keep a balance between theory and practice and the flexibility to allow improvements in curriculum, content and structure.

The share of renewable energy sources in the global mix of energy supply has seen a significant increase recently leading to a growth in the demand for skilled workers in renewable energy systems which requires developing innovative curricula, courses and laboratories (Kandpal & Broman, 2014). Teaching sustainability and alternative energy in today’s engineering curriculum has increasingly become an essential feature, where both areas require multi-disciplinary-problem-oriented and project-based learning approaches (Belu & Husanu, 2012).

The purpose of this paper is to show how the knowledge of academia and industry in the aquatic renewable energy sector in Colombia can be integrated to lead to a sustainable “industry-academia knowledge transfer (IAKT)” model. This model uses as a reference the successful British IAKT model which has sustained a productive academia, industry-government interaction over the past two decades. In particular, this study will focus on the British programme run in the Orkney islands that has helped position the UK as a pioneer in the marine renewable energies sector.

In addition, some of the steps taken in Colombia to respond to the increasing challenges in the environment and education are analysed—particularly at Universidad Cooperativa de Colombia—as well as some actions towards the long-term development of strong relationships with industry that permeate the education and research programs offered.

The information obtained is based on information taken directly from the primary source through personal interviews and direct observation; secondary sources as well as international literature were also reviewed.

In summary, the objective of this work is to propose a knowledge-education model between the academia and the industry for aquatic renewable energy development in Colombia and to review the results of initial deployment in terms of the skills developed by the students in both technical and soft management areas such as communication, teamwork, critical thinking.

2. Methodology
This section of the paper is divided into two areas.

Firstly, some of the aspects that have contributed to the innovation and technology development in the aquatic renewable energy sector in the UK are identified and discussed. This information was obtained through direct interviews performed during a visit to Orkney islands in Scotland, a place with a global role in driving the exploitation of marine energy and having probably one of the best global wave and tidal resources (Hibbert, 2010).

Secondly, an analysis and review of recent progress made in Colombia in the renewable energies sector including the development of an education programme at the Universidad Cooperativa de Colombia (UCC).

As a result, a knowledge-education transfer model for aquatic renewable energy was proposed for application within the UCC MSc in Energy approved by the National Ministry of Education, which is explained in section 3.

2.1. Identification of lessons learned from the Orkney islands, UK, case study

2.1.1. Relationship between the industry and the academia
The starting point was to create and sustain good relationships between the industry and academia over time. There is no a “magic recipe” and rather is based on understanding and appreciating what both parties have to offer. Understanding the differences between the two sectors and the
stereotypical views of each other is a key point. For instance, industry people are normally seen by academics as being profit-oriented and motivated to commercialise established practices rather than creating new ones. Academics are seen to be motivated in moving personal interests forwards and are believed to be removed from reality, self-centred, knowing little about the real world and not effective in doing or understanding business.

These points of view must be considered as over-simplified stereotypes of the reality for the construction of a good relationship. The type of relationship observed during this study was free of stereotypical views, based on respect and appreciation of what the other party can contribute to beneficial team-outcomes.

2.1.2. A world well connected
The world has, during the last decades, experienced enormous transformations in the way information is communicated and exchanged. At present, the world is globally interconnected; people may access remote laboratories and libraries and may access information content that better suits their needs. This has brought changes in areas such as purchasing, education, work or business, just to mention a few; in addition, you can enrol in a distance-learning course, use the internet for the commercialisation of a new product or work as a consultant and collaborate with any other consultant anywhere in the world. These changes have improved the way academia and industry can interact and cooperate. Projects in aquatic renewable energies take place in different places around the world, where the use of the internet and global communications have brought enormous advantages in facilitating dispersed project teams communicating and collaborating in near-real-time.

2.1.3. Curriculum in academia
The curriculum offered by academia has an important impact on the innovation process. A close collaborative relationship between Aquatera Ltd. and Heriot-Watt University (HWU) on marine renewable energy education and research development projects in the Orkney Islands has been studied to understand better the likely factors for successful knowledge transfer. Aquatera has hired more than twenty students since the beginning of the HWU MSc in Marine Renewable Energy was launched. This was a direct result of a good, collaborative relationship being built between a company and the university, and by the close involvement of the industrial partner in planning and development of academic course content and processes.

Both organisations have offices in the same building where co-location has facilitated a permanent and ongoing discussion between both parties to define a target curriculum and the skills that meet the industry needs. As a result, the company knows the kind of syllabus and skills students end up having after a master course and the students know what to expect from their future employees. This is very valuable for the company as it leads to them being able to employ the most suitable students to meet their capability needs.

It is also important to ensure that the courses are updated regularly by the universities in-line with developments in technical and managerial understanding to guarantee the most pertinent experience to students. Education should focus on the development of skills, behaviours and capabilities. Behaviours and attitudes such as being proactive, collaborative and self-motivated are considered by the companies to be important characteristics for professionals of the future.

Another aspect to be considered is related to the place where the course is offered, as this may have an impact on the students’ life and their appreciation of deployment and development issues for their skills and knowledge. This attribute was addressed when HWU located delivery of the master course in the Orkney island, a place where sustainable marine energy is actively being developed and providing employment, i.e. it has a real meaning in people’s life.
2.1.4. Project-oriented vision

Once the relationship has been built, both academia and business can cooperate in a joint project. This has been the experience of the marine industry developed in Orkney, where the expertise and excellence of the academia has been combined with the pioneering vision and innovation of the industry partners. This relationship has been enriched by bringing talents and excellence from the government and local communities whilst understanding their limitations. The key point is to look for opportunities based on the co-creation of intellectual and physical assets of each of the participants in a project.

2.1.5. Spin-off companies

Spin-off companies are good examples of how a relationship between sectors becomes a reality. In these companies, the excellence of the partners is used whilst working on the leading edge, pushing things forward, exploring new ideas and developing new products. The European Marine Energy Centre (EMEC), a company born as a spin-off and initially with ten-year investment to focus on researching new ideas. This kind of company could be compared to a project of building a road. First, the road is planned, which can be thought as an activity led by the academic partner; then, the road needs to be built which is the role of the industry partner. Moreover, when the question arises how to expand the road, it falls to the business to lead this process, which is normally more flexible than the academic partner. A necessary skill is to be courageous as working for a spin-off company requires working on the edge, pushing boundaries and being prepared to see no profit in the first years of business.

2.1.6. Testing the new ideas

The question here is how companies do innovation, and what the process is for making contacts and demonstrating their ideas. If the idea is good enough and the return fast, one of the options is trying to get funding from sectors like the government or the public who are generally oriented to support the traditional ways of working. However, whenever the new idea has first to be tested, the challenge for the company is different. First, the return on investment takes longer or building sales is not an option open to the company. This is a case where traditional ways of working are not applicable and where a better option is to encourage small and medium businesses to grow first before selling, therefore retaining the new ideas within the company. This creates diversity and retains innovation within the company. Innovation could be misunderstood as an unexpansive process and achieved through quick deployments. This can become untrue whenever business-community-government-academia is distributed in dispersed locations and are a decentralised cluster.

2.1.7. Understanding the sector

To innovate in a sector, it is necessary to get a true understanding of the characteristics of that segment of the market.

The aquatic renewables energy sector has specific attributes such as its close relation with the communities and their surrounding environment, which involves a careful analysis of the socio-economic conditions. This was analysed and understood by both the universities and companies. It requires careful consideration of local conditions such as local economy and market, planning, engineering, and policies, to propose the most suitable solutions for a specific context. Understanding the economics and market involves appreciation of the customer, communication, and discussion with people to recognise what their real needs are, whilst planning skills are meant to propose smarter solutions rather than over planning. Engineering challenges, to name a few, include the selection of the correct materials, the investigation of structural forces, energy conversion processes, energy storage, foundation design, geotechnical and hydrodynamic. All these considerations are necessary to create a system that generates smart solutions while considering the environmental appropriateness.

2.1.8. Internationalisation

People involved in projects inside the aquatic renewable energy sector have at some point to travel and get to know the place where the project is taking place. This creates an opportunity for
networking, and the possibility of working from abroad. For this, it is necessary to know very well the place, people, procedures, and programmes to equip people to work overseas. The use of the internet has proved to be of substantial help in facilitating people working on projects in this emerging industry.

2.2. Current situation within the UCC toward aquatic renewable energy

Progress has been made in Colombia to develop some of the points identified as decisive to achieve competitiveness in the aquatic renewable energy sector as achieved in the UK. The relationship between the industry and academia has been strengthened through the development of projects between industry and universities in the UK and Colombia sponsored by the British Newton Fund via the Royal Academy of Engineering under the Industry Academia Partnership Programme (IAPP).

The UK–Colombia IAPP funded by the Newton Fund/Royal Academy of Engineering aims to strengthen capacity and develop capabilities within Colombian engineering higher education and research institutions to enhance their engineering education, research and innovation output through the strengthening of industry linkages and leveraging UK expertise.

Under the leadership of the Universidad Cooperativa de Colombia (UCC) in alliance with Aquatera Ltd., Heriot Watt University and COTECMAR (Colombian ship and floating platforms builder) three initiatives have been approved by the IAPP: Accelerating Marine Energy in Colombia (2016–2017), Identification of Knowledge Gaps in the Academia and Capacity Building for Aquatic Renewable Energy in Colombia (2018–2019) and Enhancing Aquatic Renewable Energy (ARE): Technology design and adaptation programme for Colombia (2019–2020). The latter project collects some of the key findings of the first two projects.

The run-of-river, floating solar, offshore wind resources were identified as the main, potential renewable resources in Colombia with some interesting niche markets including coastal and river-based, off-grid communities’ electrification, which are highly aligned with the Colombian Government aims. The aquatic renewable energy technology design and adaptation will strengthen one of the gaps identified during the previous awarded projects. UCC will lead in the development of a targeted capacity building programme for UCC on the design and adaptation of the technology to align to Colombian conditions, in partnership with COTECMAR as a national industrial partner and HWU and Aquatera both from the UK.

Progress in these initiatives has been achieved with the application of management tools and specific products to support developments by the participants. The development of this project provided the opportunity to strengthen the teaching, research and innovation capabilities in aquatic renewable energy of Colombian participants, particularly researchers at the UCC drawn from diverse backgrounds such as social science and engineering. This multidiscipline team were considered necessary to address multi-faceted questions relating to teaching and learning methods to support technology knowledge transfer, innovation processes, social empowerment, resource management, smart grids, business models and policies, i.e. the solution required a truly interdisciplinary approach. The consequence has been the consolidation of the critical mass of the necessary skills and disciplines drawn from the students and professors of different UCC programs, which itself has attracted the attention of instrumental stakeholders from government, industry, NGOs and vulnerable communities.

3. Results discussion

As a strategy to foster processes of knowledge and technology transfer, and looking to implement academic programs relevant for the industry in Colombia, the UCC developed an educational model focused on the development of skills in three dimensions (known as competences-oriented educational model) which are knowing, being and doing (Unigarro-Gutierrez, 2017).
Colombia is a country located in the northwestern end of South America having 928,660 km² of oceans and 2,900 km of coastline with a population close to 48 million people. Its geographical position makes it the only South American country with coasts on both the Caribbean Sea and the Pacific Ocean and major rivers (Figure 1). There are very important geographical and social differences in these coastal regions. The Colombian Caribbean coast is a very dry region, with a high mean temperature, scarce rain, and high values of solar radiation. Most of the coastal development of Colombia is located in the Caribbean. A considerable part of the population lives in the Caribbean Region, and there are important cities located along the coast (Figure 2). There are several large rivers in the Caribbean coasts, as it is the region where all the precipitation from the Colombian mountain ranges drains to (Figure 3). These rivers flow into the Caribbean Sea forming deltas because the geomorphologic processes are ruled by the river dynamics as there is a very low tidal range present (~40 cm).

Bearing this in mind, using the expertise in aquatic renewable energy of the consortium partners and considering the power potential of water resources in Colombia (Colmenares-Quintero, Benavides-Castillo et al., 2020; Osorio et al., 2016) the UCC has proposed an elective course in aquatic renewable energy within its MSc in Energy which was approved in 2018 by the Colombian Ministry of Education. The partners will be acting as validators of the course syllabus.

**Figure 1.** Map of Colombia in South America and Exclusive Economic Zone (EEZ).

**Figure 2.** Population density in Colombia.
The UCC MSc program in Energy offers professionals in engineering and related areas, specialised training that develop the necessary skills required by the industry. These focus on energy efficiency management using traditional and alternative sources, and emphasising the techno-economic framework for analysis and design of energy and environmental management life cycle systems that exploit sustainable models within industrial processes. Its content is determined by the techno-economic and environmental analyses as well as by the optimisation techniques in the energy field, and allow the student to integrate into the professional world in the public or in the private sector, participate in research projects, by innovating in industrial energy processes or by generating their own business projects. Table 1 summarises the skills and courses designed for the master course.

Table 1. Skills and courses for the MSc in Energy designed at the UCC with collaboration of the national and international partners

| Macro-skills                                                                 | Micro-skills                                                                 | Course                                                                 |
|------------------------------------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| Propose and execute integral solutions for the efficient use of energy while preserving national and international quality standards | Evaluate processes and equipment to determine their feasibility by implementing new energy alternatives under technical, economy, and environmental parameters. | Sources of generation technologies and energy processes Transport phenomena |
| Modelling energy systems for the improvement of the efficiency of energy devices using optimisation tools | Process and modelling optimisation Conventional sources of power generation Alternative sources or power generation Fuels and combustion |                                                                                       |
| Design improvement plants for the increase of feasibility of energy systems using tools from the field of engineering | Design of experiments Thermal machines Biotechnology applied the energy processes Gasification processes |                                                                                       |
| Analyse life cycles to include the rational and efficient use of energy in conventional and alternative energy systems using tools that integrate technical, economic, environmental, and social indicators | Life cycle analysis Energy legislation applied to conventional source Energy legislation applied to alternative source Energy legislation applied to biotechnological processes |                                                                                       |
| All micro-skills                                                              | Elective in Aquatic Renewable Energy (ARE)                                 |                                                                                       |
As a deliverable of the second project sponsored by the Newton Fund/RAE in 2018–2019, an elective course on aquatic renewable energy (ARE) was designed, and feedback was given by the industrial partners based on their actual needs. The design of the overall curriculum has the overarching principle of integrating technical knowledge with social, economic, and environmental assessment skills to address the challenges of both vulnerable communities and industry (Colmenares-Quintero, Benavides-Castillo et al., 2020; Colmenares-Quintero, Rico-Cruz et al., 2020). This approach recognises that the energy sector requires professionals who have a wide, cross-industry knowledge and skills in addition to technological/engineering-based skills—including resource assessment, ecological impact evaluation and monitoring, financial appraisal, planning, policy development and logistics (Rojas & Colmenares-Quintero, 2018).

Tables 2, 3 and 4 summarise the main components which may be included within the ARE course. The approach is based on a common format for each of the aquatic resources—including Wave, Tidal, Offshore Wind, Run of River, Aquatic Solar, Ocean Thermal Energy Conversion (OTEC), Aquatic Biomass, etc.

The proposed course components have been grouped under the following headings:

1. Renewable Energy Resource.
2. Technology.
3. Policy/Economics.
4. Project Appraisal.
5. Environment.
6. Energy Systems.

### Table 2. ARE resources topics for the course

| Course Topic | Component | Course elements | Justification |
|--------------|-----------|-----------------|---------------|
| 1. ARE Resources | 1.1. Origins of the Energy Resource and Energy Transformations. | | To develop an understanding of renewable energy resource formation processes. |
| | 1.2. Nature of the Energy Resource and local modification. | | To develop an understanding of local resource conditions, how they are modified and ideally enhanced to form an economic development site. |
| | 1.3. Power relationships, key variables, and Units. | | To build on the knowledge of Energy Resource Formation (1.1) the Power relationships and the key factors in power availability should be covered. |
| | 1.4. Resource Variation—Major Periods. | | To understand the major cycles of energy availability. |
| | 1.5. Typical and Extreme Resource levels. | | To develop an understanding of the Resource Variation—locational, spatial, and temporal characteristics. To understand the nature of economic sites where the resource is generally enhanced. To understand the range of fluctuation levels which has significance to the constantly varying amount of energy extracted and critically to structural design loads and aspects such as moorings. |
| | 1.6. Quantifying the Resource (Data Monitoring and Modelling techniques) | | The importance of prospecting the environmental flows in sufficient detail to accurately predict the sustainable level of energy which can be extracted without damaging the resource or environment. The instrumentation used to gather data and modelling techniques. |
Table 3. ARE technology, policy, economics, and project appraisal topics

| Course Topic                      | Component                                      | Course elements                                                                                                                                                                                                 |
|----------------------------------|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2. ARE technology                | 2.1. Status and Maturity.                      | To understand the current status of technology and where appropriate the latest R&D. Technology Readiness Level (TRL).                                                                                           |
|                                  | 2.2. Scales of Technology and Developments.   | Importance of recognising the different scales of technology which are appropriate to householder, community and strategic power generation markets involving “micro”, “small” and “large” generation plants. |
|                                  | 2.3. Technology interaction with the resource. | To develop an understanding of the types of external forces which must be considered as part of the engineering design process. In normal operating conditions, acceptable forces are applied to the technology to enable extraction of energy, however an appreciation of the “worst case” loading to be resisted must also be considered. The mechanisms of limiting loads and energy extraction should be addressed. Floating solar structures will require the loadings from fluid flows to be analysed. Tidal and River turbine blade require the effects of turbulent loading to be assessed. |
|                                  | 2.4. Design Basis for Marine Energy Conversion.| To consider the structural design options and engineering principles.                                                                                                                                                |
|                                  | 2.5. Research and Development (R&D).          | Technological advancements continue to place throughout the renewable energy industry such as increased physical scale/power output in wind energy, deployment innovations such as aquatic PV projects in Solar and with the wave sector an entire R&D industry. |
|                                  | 3.1. Climate Change policy.                   | International climate change policy is a key driver for the renewable energy. Similarly considering how ARE contributes to UN Sustainable Developments Goals. This sets the wider policy contexts for renewable energy development. |
| 3. ARE Policy and Economics       | 3.2. National/Regional Energy Policy.          | Any supranational targets to which the nation (Colombia) has committed as well as national targets should be covered. These are obviously important key drivers for renewable energy development at the national level. Also, any social or (regional) economic development policy relevant to renewables. |
|                                  | 3.3. Planning Policy.                         | This would include nature conservation designations. This may be of high or low importance depending on the national situation.                                                                                       |
|                                  | 3.4. Economics.                               | Basic microeconomics. Demand & supply, individual firm under perfect market competition and monopoly. Basic Macro Economics.                                                                                         |
|                                  | 3.5. Environmental Economics.                 | The concept of market failure and externalities. Environmental assessment.                                                                                                                                         |
|                                  | 3.6. Market Intervention.                    | Subsidy regimes. Specifically Feed in Tariffs, Renewables Obligations; Contracts for difference; tax subsidies, etc.                                                                                               |
|                                  | 3.7. Energy Markets.                         | Describe regional specific situation for trading energy.                                                                                                                                                           |
| 4. Project Appraisal             | 4.1. Energy Costs.                            | The Levelised Cost of Energy (LCOE) has become the standard tool for comparing the costs of different energy generation technologies. It is important that graduates are, at least, familiar with the basic terminology. It is important to stress both the strengths and weaknesses of the methodology. |
### Course Topic | Course elements |
|---------------|----------------|
| **Component** | **Justification** |
| **4.2. Appraisal techniques.** | Net Present Value and Internal Rate of Return. Describe basic methodologies. Decision making criteria. Conflict between the two methods. How to deal with mutually exclusive projects and, in the case of IRR, dealing with complex cash flows. |
| **4.3. Project finance.** | Source of funding (internal and external). Explore the relationship between risk and return (and views taken by different sources of finance). |

### Table 4. ARE environment and systems topics

| Course Topic | Course elements |
|---------------|----------------|
| **Component** | **Justification** |
| **5. ARE Environment.** | **5.1. Effect of energy extraction on the environment.** Understanding the role of energy in ecological processes and the results of its extraction. Also review the potential physical impacts of project (e.g., collision risk). |
| | **5.2. Social and human impact of energy extraction.** Understanding the potential human impacts of energy projects. |
| | **5.3. Environmental impact assessments.** EIA in international Law Colombian Law. |
| | **5.4. Lifecycle Energy and Carbon Assessments.** Principles of lifecycle assessment. Lifecycle carbon/energy in renewable and conventional energy sources. |
| **6. Energy Systems.** | **6.1. Grid Integration.** The main integration route for ARE developments will be either the main utility grid or localised mini-grid systems. |
| | **6.2. Storage.** Storage of energy either prior to transformation in technologies such as hydro, or energy storage after transportation in batteries, heat, or fuels such as hydrogen. |

For initial validation of the ARE course, an exercise using a project-based learning (PBL) approach with some UCC undergraduate engineering students was carried out. This activity was supported by the industry partners, COTECMAR and Aquatera Ltd, and the British academic partner, HWU, as validators. A group of four students from different engineering disciplines were given a challenge of developing sustainable energy supply for a vulnerable, Colombian community, and the knowledge and practical skills needed to solve it. During this process, the students analysed costs, preliminary system design, barriers, and opportunities to implement the production of renewable energies, using a source that could be solar, wind, marine or biomass. The project starts running the second week of classes and continues during the entire semester with three phases were the group must present their project findings to a panel from industry, academia and one of the vulnerable communities. The results were very promising in terms of the skills developed by the students, not only in technical areas but also in the communication of results, teamwork, critical thinking etc.

### 4. Conclusions and future work

The transfer of knowledge via industry-academia collaborations in the renewable energy sector in Colombia is still under development. Although the assessed potential of the aquatic renewable
energy (ARE) is not as high as in other Latin-American countries, it is an energy sector that can play an important role via small and medium scale projects and of high relevance in the context of the UN Sustainable Development Goals.

The ARE sector requires the development of specific skills. Therefore, lessons learned by the Orkney Islands case study are currently being transferred to the Colombian context and more specifically to the UCC where the knowledge-education transfer model was tailor-made for the Colombian context. This model was based on ARE course topics and validated in a preliminary phase with UCC undergraduate engineering students from different disciplines. The results were very promising in terms of the skills developed by the students, not only technical but also in the communication of results, teamwork, critical thinking and so on.

The future work will be based on developing a teaching and learning methodology in the UCC engineering programs based on these results. Validation will be done with different stakeholders such as industry, government, and vulnerable communities through interviews, workshops, and co-creation. Bearing this in mind, further work will be carried out to characterise the needs of these stakeholders and a curriculum will be established by the UCC focused on improving the skills of engineering students to solve the challenges of sustainable development for these key stakeholders.

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