Int. J. Engng Ed. Vol. 23, No. 2, pp. 266–275, 2007
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Educating Engineers in Sustainable Energy Development: an Interdisciplinary Approach*

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Sustainable energy development is satisfying the energy needs of the present generation without compromising future generations in satisfying these same needs. It encompasses three areas: economy, environment and society. Producing energy in a sustainable manner can be accomplished through energy efficiency and renewable sources of energy, among others. Sustainable energy education must be structured in an interdisciplinary manner whereby engineering modules are complemented with legal, social, economic, managerial and environmental coursework. Seminars complement academic instruction. Developing skills in these non-engineering areas is achieved through group projects with non-engineering students.

Keywords: sustainable development; energy; masters; University of Calgary; OLADE; LAC

INTRODUCTION

FUNDAMENTAL CONCEPTS are involved in educating engineers in sustainable development. Those that govern sustainable energy development are particularly important. For a long time engineers have been accused of neglecting the social and environmental consequences of their work. The standards for acceptable engineering practice are evolving with improved environmental legislation and increased focus on ethics. As such there must be efforts to bridge the gap between sound technical and economical design and the people and environment that should ultimately benefit from engineering.

This paper focuses on the Master of Science in Energy and Environment programme offered by the University of Calgary (U of C) and the Latin American Energy Organization (OLADE). This programme is open to a wide variety of disciplines. The varied course content seeks to cover the environmental, social and economical aspects of the energy industry in Latin America and the Caribbean as it fits into the wider global industry. The programme is unique because it partners a traditional educational institution, the University of Calgary, with a regional governmental energy organization, the Latin American Energy Organization (OLADE).

This project arose from the need to consolidate and support the efforts being made by countries in Latin America and the Caribbean to guarantee the development of their energy industries using techniques and procedures that are compatible with the clean, efficient and sustainable use of resources. Thus, it is essential to permanently and systematically promote, at the regional level, the training of specialized professionals in energy industry disciplines and environmental control, management and protection. The involvement of OLADE is seen to be critical since it gives students instant access to data, publications and expertise in OLADE. The organization is ratified by twenty six (26) member countries of Latin America and the Caribbean and was created because of the need to establish a cooperation mechanism among the region's countries to develop their energy resources, and, at the same time, implement measures for the efficient and rational use of these resources to contribute to the region's economic and social development [1]. Within this context, OLADE was established as a cooperation, coordination and advisory agency, with its own legal status, essentially aimed at promoting the integration, development conservation, rational use and marketing of the region's energy resources. This mission would position OLADE as a useful partner for an education facility in the development of sustainable development education in the region.

Regional programmes such as this one have surfaced in Europe. Since 2000, a European Master's programme is offered in renewable energy [2]. This corresponds to a regional effort to develop renewable energy in Europe. The programme focuses on technical and economic aspects of renewable energy sources. There are more than five partner universities where each one trains students in one specific renewable technology. The programme is designed to present

* Accepted 11 February 2007

core courses in wind, solar, bioenergy and water. These are later followed by courses specializing in bioenergy, hybrid systems, photovoltaic, solar energy in the built environment and wind energy at partner universities. A final project is also presented. Most courses have laboratory reports, exams and projects.

BACKGROUND

Sustainable energy development

Energy is a modern day necessity. Countries develop using energy. Industries are powered by energy. Daily human activity could not be carried out without energy. In essence, energy is vital for social and economic development [3]. For example, in 2001, the global electricity consumption per capita was 2,361 kWh, an increase from 1,573 kWh in 1980 [4]. This is a steady increase and will continue in the future. The issue is whether countries can use energy resources wisely without compromising future development of these energy resources.

The concept of sustainable development has therefore been formulated to address this issue. The milestone definition of sustainable development appeared in 1987 with the Brundtland Commission's report *Our Common Future*. Sustainable development is:

> Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [5].

In the context of energy development, sustainable energy development could be defined as energy development that meets the needs of the present without compromising the ability of future generations to meet their own energy needs. Experts from international organizations such as the World Bank and the United Nations suggest that sustainable development is a balance between social, environmental and economic objectives as shown in Fig. 1 [6]. These same principles are applicable to sustainable energy development.

Figure1 demonstrates that sustainable energy development entails an interdisciplinary approach. Ergo, when instructing engineers in sustainable energy development, these three areas must be covered. These three aspects must be balanced because any bias towards one given area may jeopardize the successful completion of a project. An understanding of the fundamental social, economic and environmental issues allows a better understanding of the driving forces and barriers of a project along with the interests of the stakeholders.

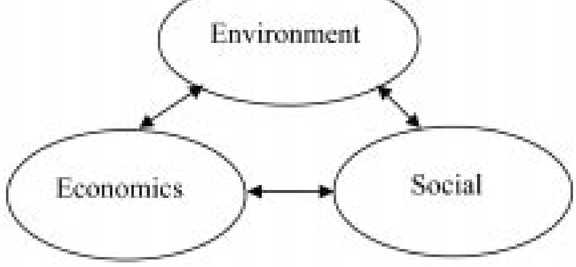

Fig. 1. Sustainable development is a balancing act.

Engineers play vital roles as project managers and project engineers on projects where employees may come from different geographical and cultural settings. The energy industry is a global industry; in LAC there is a wide mix of multinational, national companies and NGOs. It is therefore important that engineers are able to carry out their roles in these diverse settings. Additionally, it is important to understand the needs and values of project proponents and beneficiaries, and the various social impacts or benefits of energy projects. Many of these issues are not formally taught in engineering courses.

Figure 2 illustrates the extended areas sustainable energy development must address. Engineers involved in energy projects must be trained in the economic, engineering, environment, legal, management and social aspects of energy projects.

Case study

In 1996, U of C and OLADE initiated a Master of Science programme in Energy and the Environment, with the support of the Canadian International Development Agency. The programme targets high potential professionals from the LAC region working in the energy sector. Although engineers account for almost 50% of the student population, other disciplines are welcome. These include professionals from various countries in the region and Canada, with diverse academic and professional backgrounds. The programme is offered in Quito, Ecuador where OLADE is headquartered. The University of Calgary is located in Calgary, Canada. The duration of the programme is 15 months.

Programme objectives

The principal purpose is to provide students with the necessary understanding and skills required to oversee energy projects and operations in agreement with sustainable energy principles. Moreover, the students obtain skills needed to successfully implement energy projects. These skills include [7]:

1) Planning the environmental components of energy projects;
2) Incorporating environmental factors into energy development plans and strategies.
3) Designing and implementing environmental protection standards and procedures for the energy industry;
4) Implementing environmental protection policies in energy development;
5) Coordinating environmental impact assessment and forecasting studies;

6) Conducting and supervising environmental audits in energy project development;
7) Conducting technical, financial, economic, and social assessments of energy programmes and projects, within an environmental context;
8) Skills and behaviour for leadership and management of effective energy development projects;
9) Working in cross-cultural/interdisciplinary energy project teams.

In order to fulfil these objectives the training received goes beyond the basic technical training an engineering student receives during his/her undergraduate or graduate preparation. The Haskayne School of Business of the University of Calgary manages the programme, so management training is emphasized. Students therefore develop practical skills in areas that would benefit their professional development such as presentation and communication skills and teamwork. Engineering programmes are often criticized for a lack of development of these types of skills that are important in the workplace. The LAC region is blessed with a rich mixture of cultures, hence varied values and perceptions. Engineers working in the energy sector in LAC must be well-rounded professionals, able to function effectively in diverse situations.

Programme structure

An introductory week familiarizes students with the U of C and OLADE, and gives an overview of the programme's content and objectives. Presentations are made by the programme leaders on current issues in sustainability, energy development in LAC and Canada, and the role of OLADE in the LAC region. One group activity carried out during this week is a game based on 'cultures'. Programme participants are divided into two groups or cultures. Each culture is given a set of rules that embody their culture or way of life. Ambassadors are sent to the other culture to interact and to try and establish a link. This exercise illustrates the fact that there are many points of view and beliefs and these differences may often be as a result of cultural backgrounds. It is often hard to understand and assimilate philosophies that at times may conflict with a person's way of thinking. It also demonstrates that patience is very important when trying to learn and comprehend a different culture. This is particularly true when dealing with indigenous populations in oil and gas projects. Bolivia and Ecuador have had problems recently due to extraction of fossil fuels from their native territories. In this case, understanding TEK (Traditional Ecological Knowledge) is important. TEKs are the beliefs and values of native or indigenous populations based on ancestral and ecological knowledge and are usually passed down by oral traditions.

Since the course is interdisciplinary, upgrade courses are offered at the beginning of the programme after introductory week so that the students can review key concepts in chemistry and economics. For some this is a review and for others it is exposure to new material but necessary for preparation for the courses to follow.

Table 1 summarizes programme courses and gives a brief description of each. These 14 courses are compulsory and must be completed before graduation. Each course is worth .5 full course

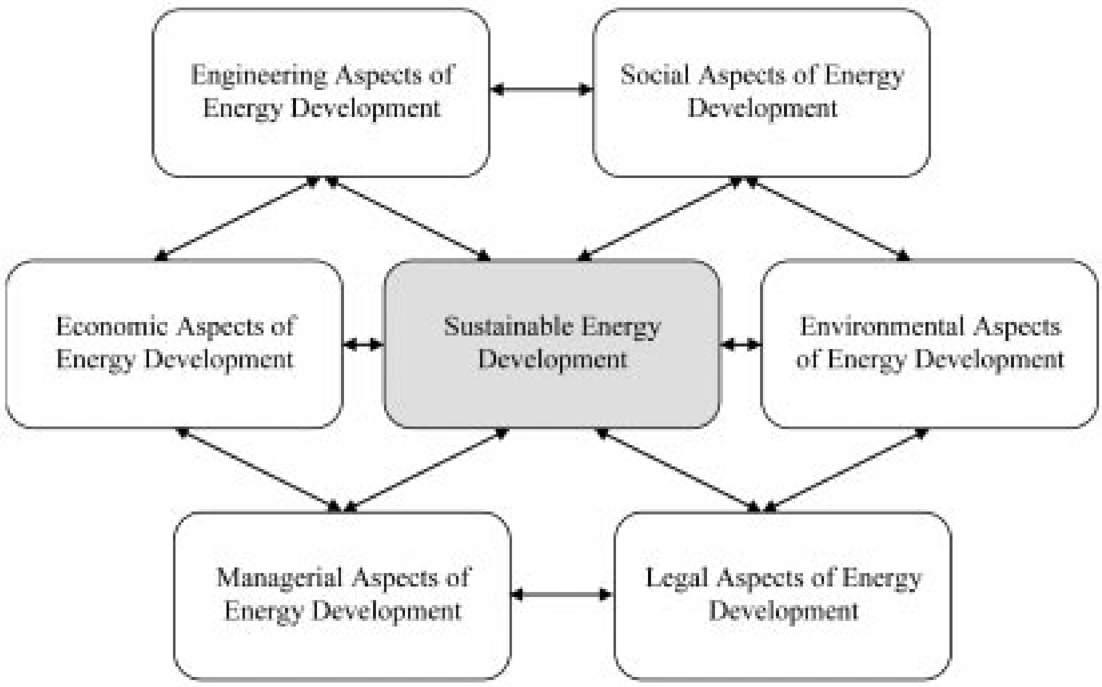

Fig. 2. General roadmap for designing sustainable energy programmes.

Table 1. Course name and description

Course Name	Description of Main Topics Covered during course	Areas covered by Course
Energy Systems I: Nonrenewable Energy	Source of nonrenewable energy: coal, oil, gas; Phases: exploration, production, operation, abandonment; Environmental impacts of nonrenewable source; Energy Economics; Gas Usage	Economics, Engineering, Social, Environment
Energy Systems II: Renewable Energy	Source of renewable energy: solar, wind, biomass, geothermal, ocean, cogeneration, micro hydro generation; Technical evaluation of renewable energy projects; Economic evaluation of renewable energy projects; Rural electrification: energy use and demand; Cultural aspects of renewable energy projects; Skill levels in renewable energy projects	Economics, Engineering, Social, Environment
Air Pollution and Its Impact in the Energy Sector	Sources and consequences of air pollution; Population growth; Managements and technologies for air pollution prevention; Mitigation and control measures for energy projects; Gaussian dispersion model, Acts	Engineering, Environment, Legal
Land Pollution and Its Impact in the Energy Sector	Integrated solid waste management; Landfill options; Soil remediation of hydrocarbon contaminated sites; Biofilters; Risk assessment; Climate Change; Carbon offsets; Clean Development Mechanism (CDM)	Engineering, Environment, Social
Water Pollution and Its Impact in the Energy Sector	Sources and consequences of water pollution; Wastewater management and water pollution prevention; QUAL2E EPA model for water modeling; Methane extraction from wastewater treatment plants	Engineering, Environment, Legal
Energy Systems III: Planning and Energy Economics	Finances and technical evaluation of projects; Planning and investment options; Economic Regulation; Natural Monopoly; Case studies in energy sector: California, Brazil, Alberta	Economics, Management
Environmental Impact Assessment (EIA) in the Energy Sector	Scoping, Screening, Impacts Prediction and Assessment, Mitigation, Follow-up; Principles of EIA; Definition of adverse effects, cumulative effects; Valued Ecological Components (VEC); Public participation and consultation	Economics, Social, Management
Human Resource Management in the Energy Sector	Productive systems in human resources, synergy; Managing quality control and change; Communication; Leadership; Teams; Organizational Dynamics; Personality test; Conflict Management	Social, Management
Strategic Environmental Planning for Energy Firms in LAC	Historic review of Schools of Strategy; Concepts of Corporate Strategy; Sustainable development issues; Porter's SWOT; Competitive advantage; First-mover advantage; Definitions Stakeholder and working for stakeholder interest; Corporate Social Responsibility; Case studies in strategic planning: Chevron, TransAlta, VisionQuest, Conoco	Environment, Social, Management,
Environmental Law in the Energy Sector	Kelsen pyramid: hierarchy of laws; International laws and Treaties: Montreal Protocol, Kyoto Protocol, Basel Convention, others; National Constitutions; Ministries of Energy in LAC; Ministries of the Environment in LAC; Regulation; Enforcement; Due diligence; Public participation and consultation; International Labor Organization, Rights of Indigenous populations: Native and Afro American	Environment, Legal, Social,
Environmental Management Tools in the Energy Sector	Analysis of barriers and driving forces; Strategies to overcome barriers; Strategic Environmental Management; ISO certification; Life Cycle Assessment (LCA); Environmental Indicators; Environmental Management Systems (EMS); Environmental Audits; Corporate Social Responsibility; The Natural Step; Education and training; Kyoto Protocol, CDM	Environment, Legal, Management, Social
Energy Policy	Energy Policies in the LAC region; United Nations energy goals; Energy as a means to abate poverty; National Policies vs. Hidden Agendas	Management, Social
Individual Project	Major research project carried out individually by students	Ideally Economics, Engineering, Environment, Legal, Management, and Social aspects should be covered or linked to chosen project
Group Project	Research project carried out by selected groups within the program as a well as a Progress Report on how the group performed	Ideally Economics, Engineering, Environment, Legal, Management, and Social aspects should be covered or linked to chosen project

credits. The projects are not given a grade but rather course completed requirement status. It is important to observe that these courses cover the three areas suggested by experts as critical in sustainable development and the others included in Fig. 2. The majority of courses combine two or three of these areas in some manner. For example, the renewable energy course combines the technical evaluation of renewable technologies with an assessment of energy demands. This is an example of how assessing the need (energy) of a particular group (social) is coupled with selecting the correct technology (environment) by evaluating project financing (economics).

During the programme students are expected to develop two research projects. These must be interdisciplinary and cover the technological (engineering/science), environmental, legal, economic, social and management aspects of project development and analysis. This exercise is very important because it makes the students go beyond the conventional technical thinking. Engineering students are required to consider non-technical issues that are often more important to project analysis. Part of the requirements is to evaluate a project based on environmental impacts, social impacts, to evaluate project economics, study cultural aspects, regulatory and legal aspects alongside the technical development. It is not difficult to imagine how this can help in the professional development of an engineer who must consider all of these aspects in real world engineering. The interdisciplinary aspects teach engineers the language and importance of other disciplines. Table 2 summarizes a few examples of projects developed by the students in the program. A simple perusal of these projects will show that indeed sustainable energy development is interlinked with many disciplines and subject matter.

U of C faculties participating in the programme include Environmental Design, Law, Engineering, Economics and the Business school. The programme is modular and each course lasts three weeks. Professors from universities in LAC also lecture select courses under the supervision of U of C professors attached to the particular course. Participating professors have come from Los Andes University in Colombia, Sao Paolo University of Brazil, ESPOLI from Ecuador and ITESM from Mexico. This mix of professors with different background and research interests is important because it allows the exchange of ideas and concepts in sustainable energy development and how these are being applied in different countries of the LAC region and in Canada.

Field trips complement some of the courses and serve to illustrate how theory can come into practice. This was the case of the VII Masters programme visit to the Oleoducto de Crudos Pesados (OCP Pipeline). During the course, a review was performed on the different stages of an EIA. Once the theoretical concepts were discussed and analysed in class, a field trip was planned to Mindo Rich near Quito, Ecuador. The students were able to appreciate how predicted impacts were mitigated during the operational phase of the OCP. The field trip focused on the recovery of sensitive ecological areas where the pipeline traversed protected mountainous areas. Previous programmes had included a similar visit so had the opportunity to observe previous phases of construction and operation.

Courses are complemented with seminars offered by the various faculties. Seminars are important because they allow concepts and information to be communicated to the students without having to do a full course or to worry about grades. The purpose of the seminars is twofold [7].

Table 2. Summary of selected individual and group projects from previous cohorts.

Individual Projects	Group Projects
Implementation of Renewable Energy Technologies in Cabo de la Vega, Colombia	Opportunities for Clean Technologies in the Power Sector in Selected Latin American Countries: Coal and Natural Gas Cases
Renewable Energy for Rural Electrification in Ecuador: Application to Remote Areas	In situ Electricity Generation with Heavy Crude Oil
Environmental Regulations for the Hydrocarbon Sector in the Dominican Republic	Introduction of Ethanol for Reformulated Gasoline in Ecuador
Mexican End-Use Electric Efficiency Projects Under the Clean Development Mechanism: A Back-Casting Approach to Identify Flexible Strategies Contributing to their Success	Programs for Improving Energy Efficiency and Pollution Prevention in the Industrial Sector
Public Participation Process in Electrical Projects in Peru	Electrical Interconnection Between Ecuador and Peru
The Feasibility of the Use of Solar Photovoltaic in the Production of Electricity in the Hotel Sector of Barbados	Alternative Means of Achieving a Sustainable Public Transportation System in the City of Quito-Ecuador
Cumulative Effects Assessment for the OCP Company in Nueva Loja	Remediation of Hydrocarbon Contaminated Sludge
Can the Small-Scale CDM Scheme Facilitate the Wind Energy Development in Ecuador?	The Guideline Proposal for PCB Management in the Electricity Sector
An Estimation of Energy Savings and Greenhouse Gas Emissions Reduction Potential in the Electricity Sector of LAC Countries	Electrical Generation Using Wind for Community Development in Ecuador

Since OLADE is not an academic institution, the seminars are a way to expose students to further academic instruction. Seminars introduce students to leading edge research at the U of C as a substitute for lectures, presentations or conferences offered at normal academic institutions. They also allow professors to introduce topics that may go beyond the scope of a course, but are of interest to students. Seminars last from two to four days. Table 3 summarizes the seminars offered during the Master's programme.

The programme is further complemented with a recapitulation, an oral comprehensive exam and individual and group project presentations at the end. An international field trip is provided at the end of the academic year as an opportunity to visit another country in Latin America and experience and appreciate an aspect of their energy industry.

Programme relevance

South America is rich in energy resources and the energy sector is very important for a sustainable future for the region's people. At the same time there is a lot of pressure on the governments of these countries to develop resources economically and to tackle the problem of poverty. As exploitation of natural reserves proceeds, it is likely that environmental and social considerations may be overlooked because of economic priorities. It is important to understand that the economic needs of people are related to their human needs and rights to a clean environment and quality of life. Once this is understood it is easy to see how economic development is intricately linked to environmental and social issues and cannot be separated. Engineers involved in all aspects of project development have to bear this in mind and to take regard of stakeholder considerations. The modern business environment demands this. There has been increasing concern and consensus on the need for greater environmental sustainability and on ethics and social responsibility. These are becoming very important aspects of an engineer's work. The traditional role of an engineer is therefore changing to include treatment of employees, health and safety issues, environmental issues, human rights, community involvement and development, financial issues, accountability and corporate governance and ethics. There have been numerous examples of irresponsible behaviour by energy companies in the region resulting in negative impacts both socially and environmentally; the Texaco case in the Ecuadorian Amazon can be cited.

Programme objectives are constantly addressed and reinforced during the courses, seminars and field trips. One important evaluation of these objectives is during the development of individual and group projects. The process includes a proposal and review of the proposal, a final report and presentation. Comments from academic advisers and an evaluation committee concerning the major areas set out in Fig. 2 and programme objectives are taken into account in the assessment of the projects. Depending on the nature of the projects, some areas will be covered more than others. Once the projects have been reviewed and comments made about meeting the programme's objectives, the students can proceed to research and preparation. Another important form of evaluation is the oral exam. During this exam, questions are asked regarding topics related to energy and environment. These questions are simple at first and become complex as the exam proceeds. They are also interdisciplinary, addressing various aspects of energy and environment and may include two or more areas set out in Fig. 2.

Table 3. Summary of seminars.

Name of Seminar	Topics covered
Team Building	Team dynamics, effective teams
Energy Efficiency and Demand Side Management	Managing energy needs from the user's viewpoint, Case studies in LAC
Energy Audits—Theory and Practical Applications	Cogeneration, energy savings, financing energy projects, energy audits, practical applications in two companies in Quito, Ecuador
Application of Chemical Kinetics and Reaction Engineering to Environmental Problems	Principles of Reaction Engineering, Rates of reaction, Batch reactors
Research Project Methodology	Steps in researching a projects-applicable to individual and group project requirements, selection of a topic, selection of a supervisor, plagiarism, referencing, outlining
Environmental and Cross-Cultural Bridging: Working with Indigenous Peoples in Sustainability	Traditional Ecological Knowledge (TEKs), Indigenous people value systems, Canadian Case Studies
Environmental Dispute Mechanisms	Arbitration
Ecology Principles to Manage Energy Impacts	Application of Ecological concepts in energy projects, Ecosystems
Cost Benefit Analysis	Internal Rate of Return, Weighted Average Cost of Capital, Environmental Accounting; Case Studies
Presentation Skills	PowerPoint presentations, effective communication

In Canada, there have been efforts to measure the roles of individuals working in the environmental field. One such has been the creation of National Occupational Standards for Environmental Employment by the Canadian Council for Human Resources in the Environment Industry [8]. The Council has indicated a number of enabling competencies that are required for effective professional performance. Many of these are not taught in traditional engineering program which focuses on technical competences:

1) Communicating effectively;
2) Computer proficiency;
3) Critical thinking;
4) Leading/influencing others;
5) Learning and creativity;
6) Planning and organizing work and projects;
7) Work ethic.

Examination of the core competencies of practising engineers will reveal that success often depends on a number of soft skills. A study funded by the Government of Canada's Sector Council Program, ECO Canada (Environmental Careers Organization) through research and cooperation with practising professionals has attempted to reveal a number of essential practical skills [9]. Take, for example, environmental engineers, who according to ECO Canada require the following soft skills:

Research and analytical Observing and recording observations; Using analytical instruments and techniques to determine presence, quantity, and characterization of constituents.

Information management Critical thinking: evaluating data; Interpreting information and indicators about the health of the environment; Integrating diverse inputs (seeing 'the big picture'); Self-learning – assimilating and applying new knowledge.

Field work Operating field sampling and monitoring equipment and data recorders.

Project management Developing project/programme proposals; Developing project schedules and budgets; Managing and administering projects; Assembling, coordinating and supervising project teams; Dealing with unexpected/critical events (trouble-shooting).

Public relations Instructing, training and educating others.

Problem-solving Investigating offences of environmental regulations and bylaws; Analysing a case or situation and recommending solution(s).

Written communication Technical or scientific writing.

Verbal communication Stating one's own position clearly; Interpreting and presenting information to suit the target audience.

Computer Word Processing (MS Word, WordPerfect, etc.); Spreadsheet (MS Excel, etc.); Modelling (Quattro Pro, AutoCAD, etc.).

A number of these skills are not taught in engineering programmes. In contrast to traditional engineering programmes this course allows students to develop some of the non-technical skills required in the workplace. Some examples are:

1) Team work;
2) Presentation skills;
3) Writing skills;
4) Language skills - use of another language;
5) Understanding and tolerance of cultural differences.

This programme places the engineers in real world situations where they are expected to work alongside individuals with different training and values. This means that engineers have to act as coaches and group leaders in some of the more technical courses. This is demonstrated in the group project. The students are grouped as heterogeneously as possible considering educational background, personality, country of origin and gender. This creates a challenging working environment in which the hopes are that students rise above their differences and gain synergies and a better result in their project. Students were not only forced to work together but also to understand the group dynamics. Emphasis was placed on understanding individual personality, working style and learning style and how these differences would affect the outcome of a group task. Students had to keep track of their progress and relate it to the group dynamics in terms of individual and group behaviour. Organizing meetings, taking minutes, group leadership, assignment and accountability were highlighted. The roles and soft skills are put into practice. Engineers develop most of these skills during their work experience, but these are not formally taught.

In fact, the programme provides engineers with expertise in a number of areas they are not normally exposed to, which may allow them to direct their careers into untraditional engineering jobs such as policy development or regulatory monitoring. This not only benefits engineers in terms of job opportunities but also employing organizations who acquire engineering expertise. No doubt that there is a significant need for engineering knowledge at various levels of governmental and private operations in departments that often do not attract the engineering knowledge they need. The role of the engineer must therefore change not only to be an analyst and a builder, but also as a lobbyist for change where knowledge of legal, social and economic matters is required along with the technical knowledge that is taught in school.

This programme is unique in many ways. It is multidisciplinary and offered to students with a wide variety of academic training and professional experience. It is the only programme of its type in Latin America. The combination of public/private partnership gives the programme some competitive advantage if it can successfully combine the resources of each institution. Scholarships and work with OLADE exposes students to some of the work that is presently being done in OLADE. The use of Canadian professors guarantees the quality of teaching staff and the influence of the Canadian 'style' of teaching is beneficial. The modular structure of the courses allows for intensive learning over a three week period.

The focus on group work and the training on group work and human resources both on a theoretical and practical level will be important to professional development. Students gain respect and appreciation of other working and learning styles. It is hoped that this can be taken to the workforce. It can be seen that teamwork is very important in the energy field as engineers often work in groups including people from other disciplines. Being able to communicate and work with others is taught without stifling individual work and creativity and should be useful in the future. The presentations and group work in every course force communication skills and teamwork. The fact that the course is in English is also useful for Spanish speakers as over time they master use of the language. For English speakers it is just as important as they learn to communicate in Spanish since they have to live in an Hispanic country.

Programme analysis and performance

Sustainable energy development spans many disciplines. So, while developing a sustainable energy programme, emphasis must be placed on an interdisciplinary approach. For example, engineering coursework may give an understanding of the physical, chemical and biological processes involved in the energy industry. How these affect the population and surrounding are considered in the EIA process where predicted impacts are identified. The legal framework involving the EIA binds all three together. This example serves to illustrate how engineering can be combined with social and environmental concerns. Therefore, it is not only engineering that an engineering student must learn and understand. An engineering student must also comprehend other aspects of energy development.

Table 4 summarizes the academic background of the participants. This mix of backgrounds permits engineering students to appreciate other points of view. Appreciating non-engineering points of view is especially educational and often learning about other backgrounds helps students see the bigger picture.

Table 5 summarizes the country of origin of students from the first six years of the programme. This mix of nationalities is perhaps the most interesting aspect of the programme. By interacting with students from different countries, students can discuss energy developments in their counties of origin to draw comparisons. For example, students might discuss why Colombia has a 19.5 MW windfarm while Ecuador has had technical evaluations for six potential windfarms without actually building one. Why has this happened? Is it related to the country's political scenario? Or students might ask themselves if energy integration is possible given the varied political, social, economic agendas of LAC governments.

Some positive results are worth mentioning. A recent survey showed that 84% of the alumni had increased their career opportunities, 70% experienced an increase in their salaries and 78% had an increase in their responsibilities.

One drawback is the participation of women in the programme. While 78% of the students are male, only 22% are female. This disproportion may reflect the actual conditions of women in the energy sector in LAC. It is therefore imperative for women to have access to educational programmes. The participation of women in energy projects is a weakness in the LAC region and perhaps other developing regions.

Table 4. Academic background of participants in programmes I-VI.

Academic background	Participation (%)
Architecture	4
Biology	2
Chemistry	9
Economics	7
Engineering	58
Agronomy	1
Chemical	9
Civil	10
Computer	1
Electrical	11
Environmental	1
Forestry	1
Industrial	1
Mechanical	9
Metallurgy	1
Petroleum	12
Geology	5
Business Management	10
International Business	1
Law	2
Kinesiology	1

Table 5. Country of origin, an interesting mix.

Home Country	Percent
Barbados	1
Bolivia	2
Canada	4
Colombia	7
Dominican Republic	1
Ecuador	54
Guyana	1
Jamaica	1
Japan	1
Mexico	1
Paraguay	1
Peru	17
USA/Ecuador	1
Venezuela	4

A positive aspect of the programme is the group projects. In many of the courses as well as the group project requirement, groups follow the approach and solve diverse problems. This activity allows the students to interact in a multicultural environment as well as practice presentations, work as teams to resolve conflicting scenarios and learn about organizational behaviour [11]. Additionally, the group project serves to develop skills that are underdeveloped in many engineering students, such as social and legal skills. Although engineers receive formal training in technical skills, the nature of engineering education precludes development of other skills. This is the classical education of an engineer.

An important concern covered in various courses is that of corporate social responsibility. As future engineers and project managers engaged in the development of energy projects, it is imperative that the economic aspects of a project do not envelop other aspects of project development, such as social or environmental concerns. This is perhaps the most important component in sustainable energy course development. Integration of economic, social and other aspects with technical courses deserves special treatment.

Some of the students from this programme have gone on to important jobs in government and private organizations. Others have gone on to do doctoral studies in their chosen areas of expertise. This is one measure of the success and relevance of this programme. At the same time, however, there must be a programme for career guidance whether it is in education or job placement. The system at present is informal with students finding jobs for themselves or by professors recognizing students with the high potential for academic careers or who should seek further education. At the same time the resources of OLADE could be beneficial to graduates of this programme in acquiring regional positions.

RECENT DEVELOPMENTS

The programme has changed its name to Master of Science in Sustainable Energy Development. It will now be offered in partnership with the Universidad San Francisco de Quito (USFQ), Ecuador. Because USFQ is an academic institution, the number of seminars will be reduced seeing that, in this academic institution, students will have the opportunity to consult professors on campus as well as reducing administrative costs. OLADE will still participate in the seminars to cover such topics as energy balances, energy efficiency, energy regulatory framework, demand side management and rural electrification. The individual project will also be discontinued in order to reduce operating costs.

CONCLUSIONS

The design of a programme encompassing sustainable development must incorporate the three major areas identified by experts: economics, the environment, society and others presented in this paper. Figure 2 illustrates a generic approach to a sustainable energy programme course and curriculum development. The case study presented here serves as an example of how coursework incorporating the six areas illustrated in Fig. 2 and teaching techniques such as games, group work, field trips and peer discussions enrich the learning experience for engineers in sustainable energy development. Sustainable development programmes should be designed with an interdisciplinary approach. Some argue that sustainable science and engineering is an emerging meta-discipline [12]; as such sustainable energy development's roadmap has been introduced in Fig. 2. Engineers have an important role to play in sustainable energy development. The Accreditation Board for Engineering and Technology (ABET) defines engineering as 'the profession in which knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind [13]'. This is the ultimate objective of any type of training programme: to educate engineers for the benefit of mankind. If this education is orientated towards sustainability, it will ensure the success and the responsible use of earth's energy resources.

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