CIEE in Monteverde, Costa Rica

Course name:	Environmental Engineering for the Tropics
Course number:	ENGI 3001 MTVE / ENVI 3003 MTVE
Programs offering course:	Sustainability and the Environment
Language of instruction:	English
U.S. Semester Credits:	3
Contact Hours:	45
Term:	Summer 2019, Session III

Course Description

This introductory course presents key engineered systems that interface directly with the natural environment and strongly impact Costa Rica's economy and society via energy, water, climate and nutrient cycles. Students will investigate engineered responses to the need for managing energy, water, and nutrient flows in the production of food, fuel, and electricity. Students will compare and contrast, conventional and alternative, engineered systems for water, nutrient, and energy input and output management in crop, fuel, and electricity production. Through hands-on experiences in field settings, students will apply priniciples of resilience, optimization, and "cradle-to-cradle" toward the production of food and fuel, as well as the mitigation, minimization, or transformation of "waste".

Nowhere in the world is the imperative to design and implement sustainably engineered systems greater than in the tropics where rising consumption and populations pit people against Earth's essential ecosystem services and storehouses of biodiversity. Costa Rica is known as the little country with the big reputation for progressive environmental protection, but it faces the same challenges of other tropical, developing nations. With globalization and population growth in Costa Rica comes increased consumption and waste generation, but the engineering challenges are heightened by the reality of limited financial resources, lack of planning and ineffective governance. On the energy front, Costa Rica's current and rising demand for electricity is met mainly by renewable sources; nearly 90% of its electricity is derived from hydropower, geothermal, wind, and solar power combined. However, renewable energies are not engineered equally and some are friendlier than others to the environment, which an exploration of power plants in Costa Rica reveals in this course. Lastly, like many tropical countries worldwide, Costa Rica depends on agriculture as a principal economic activity and for food security. Nevertheless, there is variation in agricultural production in the Costa Rican countryside, and many alternatives for agricultural engineers to learn from and experience, such as composting and biodigesters to enhance soil and optimize use organic waste to increase the resilence of farms in the face of climate change.

Students can look forward to travels to northwestern Costa Rica to explore renewable energies as well as the natural wonders of the Rincon de la Vieja National Park.

Learning Objectives

Upon completion of this course, students will:

- Have command over the concepts and terminology necessary to explain the overall typical solid waste stream, recovery systems, and sanitary landfill design, operation, and levelized costs
- Have command over the concepts and terminology necessary to explain the design and operation of conventional solid waste treatment plants and be able to explain and describe their components and functioning
- Understand the basic principles of electricity generation from hydropower, wind, geothermal, and solar power and be competent at describing and explaining the function of components of power plants and wind farms of Costa Rica
- Compare and contrast, in quantitative and qualitative terms, environmental impacts of the four renewable energies, discuss and make recommendations for low-impact siting for Costa Rica
- Learn the application of linear models in the creation of possible scenarios for decision making in relation to energy planning
- Possess a foundation on which to learn more about agricultural production, especially climate-smart agriculture of Costa Rica, and when and where engineering can contribute solutions to sustainable food production systems
- Have command over the concepts and terminology necessary to explain the design and operation of biodigesters
- Have command over the concepts and terminology necessary to explain the design and operation of composting systems, with and without Efficient Microorganisms
- Have experience conducting investigation of and design for optimized compost systems for climate-smart agriculture
- Become an enlightened and engaged stakeholder in matters related to integrated environmental engineering and environmental protection, at home and abroad

Course Prerequisites

Two (2) semesters of university-level courses in the natural sciences, environmental studies, sustainability, or agriculture

Methods of Instruction

This course is taught through the use of lectures (CIEE instructors and guest speakers), discussions, field excursions, interviews, readings, and a field-based project. There are co-curricular visits to waste treatment plants, and local farms to observe and explore both engineered and natural systems. CIEE-led lectures plus associated, guided, discussions supply foundational information, concepts, and terminology, and help students make necessary connections. Guest lectures and interviews with researchers, engineers, farmers, and environmental professionals offer unusual opportunities to learn about “on-the-ground” application of engineering principles.

A supervised, field-based project will allow students to implement an engineered solution to a real-life sustainability challenge that centers on water, nutrient or energy cycles in rural Costa Rica.

Assessment and Final Grade

Attendance and class participation	10%
Agriculture field project written and oral report	30%
Energy planning lab project and oral report	30%
Final exam	30%

Course Requirements

Attendance and class participation (10%)

Attendance is noted for each lecture, discussion session, and field activity. As the 4-week session proceeds, students earn points for thoughtful commentary, questions, and participation in discussions and for attendance.

Agricutlure field project written and oral report (30%)

Students will undertake a field-based project to investigate carbon budgets of a local, smallscale farm. Working in small groups, students will then research and design systems to mitigate carbon emissions. One group will design an anaerobic digestion system (biodigester) for swine waste; another will design a composting system for organic matter. This will involve the collection of data on amounts and types of waste produced, research on design principles as well as specific details for the particular farm (dimensions, materials, siting), and protocols for management. Evaluation will be based on (1) participation in data collection and analysis; (2) an individual written report (formated for an environmental engineering, peer-review journal); (3) an oral poster (group) presentation for an audience of scientist/engineer peers.

Written report and posters must contain the following sections: Abstract, Introduction (with clearly stated objectives), Methodology, Results, Discussion, Conclusion, and Literature Cited.

Energy planning lab project and oral report (30%) Students will learn the basic theory behind linear programing as a tool for creating future scenarios used in energy planning and decision making. The program will involve the use of a linear model to create five different scenarios rellevant for Costa Rica's future. Each student will create a short powerpoint presentation (3-5 slides) to present their scenario to the group and then discuss the applications and limitations of these scenarios for decision-making. Evaluation will be based on (1) participation in data generation, analysis and discussion; (2) an individual written report (formated for an environmental engineering, peer-review journal); (3) an oral poster (individual) presentation for an audience of scientist/engineer peers.

After the poster presentations there will be a group discussion about the methodologies and results of the differen scenarios.

Written report and posters must contain the following sections: Abstract, Introduction (with clearly stated objectives), Methodology, Results, Discussion, Conclusion, and Literature Cited.

Final Exam (30%)

Students take a 80-point exam consisting of questions of multiple choice and short answer questions, and longer questions. The latter will ask students to propose low-tech, low-cost engineered solutions to (small-scale) environmental challenges that the students have become familiar with in Monteverde.

Weekly Schedule

Week 1

Unit 1: Urbanization and solid waste management in the Anthropocene

- Lecture: Environmental engineering for the tropics in the Age of the Anthropocene. The Anthropocene and the Great Acceleration, defined and characterized; global trends in urbanization, consumption, waste generation, greenhouse gas production, population growth and globalization, mirrored by national (Costa Rica) trends.
- Lecture: Solid waste management for the tropics. Plant design and function. Differences between temperate and tropical plant design, operations. Role of environmental engineering in mitigating environmental and social issues associated with waste management practices.
- Field Activities
  - Visit to Los Tajos Wastewater Treatment Facility in La Carpio
- Discussion (graded participation):
  - Can environmental engineering ensure environmental justice? The case of La Carpio
  - Anthropocene readings
- Readings
  - Castree,N. (2016) An official welcome to the Anthropocene epoch-but who gets to decide it's here?
  - Lou & Nair (2009). The impact of landfilling and composting on greenhouse gas emissions – a review.
  - McIntyre, V.N. A(2005) Modest Proposal.
  - Medina, M. (2010). Solid wastes, poverty and the environment in developing country cities: Challenges and opportunities.
  - Vansintjan, A. (2015) The Anthropocene debate: why is such a useful concept starting to fall apart?
  - Welyer, R. (2016) The Anthropocene debate.

Week 2

Unit 2: Climate-smart agricultural engineering for rural communities

- Lecture: Global environmental impacts of food production. Global land and water footprints; agricultural drivers of tropical deforestation; eutrophication; agrochemical contamination of waterways; bioaccumulation of persistent organic pollutants; anticipated patterns of agricultural expansion; greenhouse gas emissions of livestock and crops; production practices and engineered systems that reduce environmental impacts for small and large producers, including irrigation management, erosion control, biocontrol and integrated pest management, permaculture; nature as a model system for agriculture and engineering in food production;

- Lecture: Agricultural production in Costa Rica. Common production systems in Costa Rican farms: traditional smallholder polyculture, commercial polyculture, shaded monoculture, and trends toward unshaded monoculture. Common crops of Costa Rica; "thirsty" and "nutrient demanding" crops. Agricultural inputs (water, nutrients, light, pesticides and herbicides) and outputs (crop products, wastes), and their management in Costa Rica. Natural and engineered systems for the supply and delivery of inputs; natural and engineered systems for agrochemical run-off, erosion, and wastewater management.
- Lecture: Climate-smart agriculture for tropical ecosystems. Climate change patterns in the New World tropics; livestock and agricultural contributions to global CO_2, CH_4 and NO_x totals; impact of variability and uncertainty on agriculture production and practices; engineered systems for agricultural adaptation and mitigation of climate change, e.g., anaerobic biodigestion, composting with Efficient Microorganisms, carbon sequestration through agroforestry, polyculture and alternative forages, compost systems
- Workshops and assignments
    - *Field visit: Climate smart agriculture case study: Polyculture coffee in Costa Rica*
    - *Workshop 1*
        - *Lecture:* How to estimate carbon budgets on agricultural lands.
        - *Assignment:* Identify carbon emission sources and sinks for a local smallholder farm.
    - *Workshop 2*
        - *Lecture:* Principles of anaerobic digestion and digesters.
        - *Assignment, Option 1:* Design an appropriately-scaled anaerobic digester for a smallholder farm for pig waste digestion and biogas production. (Agriculture field project written and oral reports; 30%)
    - *Workshop 3*
        - *Lecture:* Compost and vermicompost principles.
        - *Assignment, Option 2:* Design an appropriately-scaled compost system for a smallholder farm for fertilizer production. (Agriculture field project written and oral reports; 30%)
- Readings
    - Ferrer *et al.* (2011). Biogas production in low-cost household digesters at the Peruvian Andes.
    - Garwood. (2010). Network for Biodigesters in Latin America and the Caribbean: case studies and future recommendations.
    - Plank. (2014). Handbook for smallscale composting facility management.
    - Preston & Rodríguez. (2002). Low-cost biodigesters as the epicenter of ecological farming systems.

- Recha *et al.* (2014). *Sustainable Agriculture Land Management Practices for Climate Change Mitigation: A training guide for smallholder farmers. Module 3.*
- Rowse. (2011). Design of Small Scale Anaerobic Digesters for Application in Rural Developing Countries.
- Tilman et al. (2011). Global food demand and the sustainable intensification of agriculture. World Bank (2016) Climate smart agriculture in Costa Rica. http://sdwebx.worldbank.org/climateportal/doc/agricultureProfiles/CSA-in-Costa-Rica.pdf

- Online Resources
  - Center for Sustaining Agriculture and Natural Resources. (2015). *Small-scale biogas technology.* http://csanr.wsu.edu/anaerobic-digestion/small-scale-biogas-technology/
  - FAO. Climate Smart Agriculture (2017) http://www.fao.org/climate-smart-agriculture/overview/en/
  - FAO. Climate Smart Agriculture (2017). http://www.fao.org/docrep/018/i3325e/i3325e.pdf

- Assignments
  - o DUE: Oral report **(**Agriculture field project)

Week 3

Unit 3: Renewable energy production

- Lecture: Energy in Costa Rica. Energy as an enabler. Consumption patterns and trends in Costa Rica; energy and IPAT; production and distribution systems in CR; transportation fuel types and sources; electricity primary sources; SIEPAC system for importing and exporting electricity; net-metering program; ntroduction to systems diagrams and energy flows.
- Lecture: Electricity: Hydropower. Hydropower principles. Potential and installed capacity Reservoir: features, siting requirements, materials and construction, longevity, maintenance. Penstock and water intake components, materials, design, maintenance. Power plant components and design: component materials; power generation machinery, control systems, connection to the electric grid; turbine system maintenance, longevity, levelized costs, end-use technology. Lecture **: The Arenal hydropower system and the proposed Diquís mega-hydropower system. Overview, comparisons of design, operation, management, levelized costs, installed capacity and land footprints. Social considerations: displacement of communities (both), including indigenous communities (Diquis); associated irrigation system (Arenal). Environmental considerations: disruptions to river ecosystems and altered watersheds; fish migrations; sedimentation; greenhouse gases. Engineered improvements in the Diquís project.
- Lecture: Electricity: Wind. Wind energy principles. Potential and installed capacity for wind power in Costa Rica. Wind site assessment and selection in Costa Rica; geographical distribution of wind farms. Spatial distribution turbines in wind farms. Turbine systems and components in Costa Rican wind farms; component materials;

power generation machinery, control systems, connection to the electric grid; turbine system maintenance, longevity, levelized costs, end-use technology. Kyoto Protocol Clean Development Mechanism and the Costa Rican wind farm expansion and technology transfer. Environmental considerations: impacts on birds, bats, other biodiversity; rare earth mining; differed greenhouse gas emissions, land footprint; water use, material and component sourcing. Turbine designs and geospatial distribution to reduce negative environmental impacts.

- Lecture: Electricity: Solar. Overview of principles of passive solar, solar heat collectors, solar thermal, and photovoltaic power. Potential and installed capacity for solar power in Costa Rica; siting assessments for future solar plants. for future Seasonal variation in solar radiation/cloudiness/rainfall and impacts on solar production; optimal panel temperature, angle for operation. Miravalles Solar Power Plant: photovoltaic panels and their components; panel orientation, power generation machinery, control systems, connection to the electric grid, plant maintenance, longevity, levelized costs, end-use technology. Environmental considerations; differed greenhouse gas emissions, land footprint; water use; sourcing materials and panels; recycling options.
- Lecture: Electricity: Geothermal. Geothermal energy principles. Installed and potential capacity for geothermal in Costa Rica. Geographical/spatial distribution of geothermal plants. Geothermal exploration, production well site assessment and selection in Costa Rica. Conventional versus enhanced production systems; vertical and horizontal drilling; Pailas Power plant and horizontal drilling under Costa Rican national park. Power plant design, function, power generation machinery, controls, and connection to the grid, longevity, levelized costs, end-use technology. Dry steam, flash steam, binary cycle power plants in Costa Rica. Brine composition, cooling, and re-injection; non-condensable gases. Miravalles III in Costa Rica: Example of technology transfer in the Build-Own-Transfer Program. Environmental considerations; differed greenhouse gas emissions, land footprint; water use; materials. Controversial plan to explore geothermal potential in national parks.

- Field Activities
  - Tour solar, geothermal, wind, and hydropower production sites in NW Costa Rica

- Discussion
  - How "green" are renewable energies in Costa Rica? What engineered features can/should be modified to make geothermal, solar, wind and hydropower greener?

- Assignments
  - DUE: Oral report (Agriculture field project)

- Readings
    - Ledec & Quintero (2003). Good dams and bad dams: Environmental criteria for site selection of hydroelectric projects.
- Online Resources
    - Instituto Costarricense de Electricidad. (2015). *Proyectos enérgicos.* https://www.grupoice.com
    - Natural Resources Defense Council. (2015). http://www.nrdc.org/energy/renewables/geothermal.asp
    - United States Department of Energy. (2015). Geothermal Energy. http://energy.gov/eere/geothermal/geothermal-energy-us-department-energy
    - United Nations Framework Convention on Climate Change. (2014). *The Mechanisms under the Kyoto Protocol: Emissions Trading, the Clean Development Mechanism and Joint Implementation.* http://unfccc.int/kyoto_protocol/mechanisms/items/1673.php
    - United States Department of Energy. (2015). Geothermal Energy. http://energy.gov/eere/geothermal/geothermal-energy-us-department-energy

Week 4

- Assignments
    - DUE: Optimal energy portfolio exercise, oral and written reports (30%)
    - Final Exam (30%)

- Reflection and Wrap-up

Course Materials

Readings

Castree,N. (2016) An official welcome to the Anthropocene epoch-but who gets to decide it's here? Hello Humans. US Department of Energy. https://theconversation.com/an-official-welcome-to-the-anthropocene-epoch-but-who-gets-to-decide-its-here-57113

Ferrer, I., Garfí, M., Uggetti, E., Ferrer-Martí, L., Calderón, A., & Velo, E. (2011). Biogas production in low-cost household digesters at the Peruvian Andes. *Biomass and Bioenergy*, 35, 1668-1674

Garwood, A. (2010). Network for Biodigesters in Latin America and the Caribbean: case studies and future recommendations. *Technical Notes No. IDB-TN-207*. Inter-American Development Bank.

Ledec, G. & Quintero, J. D. (2003). Good dams and bad dams: Environmental criteria for site selection of hydroelectric projects. *Latin America and the Caribbean Region, Sustainable Development Working Paper No. 16,* The World Bank

Lou, X. F. & Nair, J. (2009). The impact of landfilling and composting on greenhouse gas emissions – a review. *Bioresource Technology, 100*, 3792-3798

McIntyre, V.N. (2005) A Modest Proposal. Nature. Vol 343 3 March 2005.

Medina, M. (2010). Solid wastes, poverty and the environment in developing country cities: Challenges and opportunities. Working paper 2010/23. United Nations University-World Institute for Development Economics Research. Retrieved 7 January 2013, from http://www.wider.unu.edu/publications/working-papers/2010/en_GB/wp2010-23/

Plank, R. (2014) Handbook for smallscale composting facility management. SCOW. http://www.mmaya.gob.bo/redcompostaje/files/biblioteca/04%20GUIAS%20MANUALES/106%20Handbook%20smallscale%20comoposting.pdf

Preston, T. R. & Rodríguez, L. (2002). Low-cost biodigesters as the epicenter of ecological farming systems. *Proceedings Biodigester Workshop*. http://www.mekarn.org/procbiod/pres.htm

Recha, J., Kapukha, M., Wekesa, A., Shames, S., & Heiner, K. (2014). *Sustainable Agriculture Land Management Practices for Climate Change Mitigation: A training guide for smallholder farmers. Module 3.* Washington, DC: EcoAgriculture Partners

Rowse, L. E. (2011). Design of Small Scale Anaerobic Digesters for Application in Rural Developing Countries. *Graduate Theses and Dissertations.* h2p://scholarcommons.usf.edu/etd/3324

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Academy Sci.,* 108, 20260-20264

Vansintjan, A. (2015) The Anthropocene debate: why is such a useful concept starting to fall apart? Uneven Earth. A conversation about environmental Justice. http://www.unevenearth.org/2015/06/the-anthropocene-debate/

Welyer, R. (2016) The Anthropocene debate. Greenpeace bolg. http://www.greenpeace.org/international/en/news/Blogs/makingwaves/the-anthropocene-debate/blog/58262/

Online Resources

Center for Sustaining Agriculture and Natural Resources. (2015). *Small-scale biogas technology.* http://csanr.wsu.edu/anaerobic-digestion/small-scale-biogas-technology/

FAO. Climate Smart Agriculture (2017) http://www.fao.org/climate-smart-agriculture/overview/en/

FAO. Climate Smart Agriculture (2017). http://www.fao.org/docrep/018/i3325e/i3325e.pdf

Instituto Costarricense de Electricidad. (2015). *Proyectos enérgicos.* https://www.grupoice.com

Natural Resources Defense Council. (2015). http://www.nrdc.org/energy/renewables/geothermal.asp

United States Department of Energy. (2015). Geothermal Energy. http://energy.gov/eere/geothermal/geothermal-energy-us-department-energy

United Nations Framework Convention on Climate Change. (2014). *The Mechanisms under the Kyoto Protocol: Emissions Trading, the Clean Development Mechanism and Joint Implementation.* http://unfccc.int/kyoto_protocol/mechanisms/items/1673.php

United States Department of Energy. (2015). Geothermal Energy. http://energy.gov/eere/geothermal/geothermal-energy-us-department-energy