Theme: **Overview**							
Case-Study Modules							
A. Basics & Intro							
				Topic 01: Renewable Energy Basics & Intro			
				3	**Subject Content:**		
X					a.	Orientation about how this course works.	
							Course overview, syllabus, student wellbeing resources, department website, Canvas, Piazza, concept of Learning Goals (LG's).
X					b.	Renewable Energy Backgrounder / Review	
							Renewables overview, definitions (conventional/renewable/green/clean/alternative/sustainable energy), renewable energy use and growth statistics, pros and cons, employment in the renewable energy sector, renewable energy and climate, intro to other renewables not covered by this course (bioenergy, geothermal, ocean power).
X					c.	Meteorology Backgrounder / Review	
							Meteorological conventions, coordinates, Earth frameworks, timezones, jargon, thermodynamic variables, standard atmosphere, atmospheric layers.
Theme: **Hydro Power Meteorology**							
Case-Study Modules							
A'. Dam ops for heavy rain							
	B'. Hydroelect. proposals						
		C. Run of river revenue					
			D. Other issues				
				Topic 02. Hydroelectric generation			
				9	**Subject Content:**		
X					a.	Value of water	
							Worldwide distribution of water, Canadian rivers and watersheds, water availability and use, Canadian hydroelectric generation vs. demand.
X					b.	Electric grid as circuit	
							History of hydropower, large hydro dams vs. run-of-river hydro, electric power production and transmission, AC vs. DC transmission, voltages of transmission lines, distribution & home voltage, electric rates and the cost of energy. Components of a hydroelectric power system, worldwide overview of hydro vs. other electric generation system, the electric grid as a circuit. Asides: danger of electricity, aluminum production in Canada and the electricity sector, circuit diagrams and electric fundamentals.
	X				c.	Watersheds, reservoirs and dams	
							Watersheds, reservoirs, dams, intake, penstocks, turbines, names of BC watersheds, reservoir details, types of dams, examples of different dam construction and function types, dam failures, Columbia watershed is international (Columbia River treaty). Aside: hydrotechnical engineering
	X				d.	Hydroelectric turbine effectiveness	
							Calculating hydropower, power & capacity vs. energy, annual energy production, hydraulic head, types of water turbines (Francis and Pelton), electric generators. Hydroelectric dam operations: penstocks and gates, surge towers, spillways, spillway failures, negative factors in dam construction. Types of power plants: baseload, load following, peaking power, dispatchable vs. non-dispatchable. Asides: defintions of real vs. reactive vs apparent power, power factor, power triangle, videos of spillways in action, and derivation of power equations.
X					e.	Run-of-river, pump-storage, flood-storage	
							Large hydro vs. small hydro, run-of-river hydroelectric generation, pros and cons of run-of-river, pump-storage hydropower intro and types. Upstream flood storage, flood control, flood control and dynamic flood control rule curves, dispatchability, intermittent energy. Map of run-of-river hydro projects in BC. Aside: hydraulic jump
		X			f.	Snowpack & spring freshet vs. temperature	
							Snowpack, snowmelt, impact of snowmelt on streamflow, hydrographs, effect of temperatures on the spring freshet and spring flooding, rain-on-snow issues, glacier melt runoff.
X					g.	Ice jams & spring thaw	
							Freeze-up, ice jams and the spring thaw, ice fronts, impacts of ice formation on hydropower system management, extreme cold temperatures and flow constraints, subsidence warming (chinook events). Computer modelling of ice formation, supercooled water, ice formation on rivers, frazil ice, anchor ice, river "stage" effect.
	X				h.	Stakeholders	
							Water-use planning process, water use plans, stakeholders, inflow uncertainty, optimization, operational constraints including generation, flood control, fish ladders for fish migration, recreation, and First Nations issues (fishing, shoreline dust, flooding, traditional lands). Aside: example of a section of a Water Use Plan
	X				i.	Climate change, demand change and energy conservation	
							Implications of climate change for power companies, demand side vs supply side changes, conservation, variable electric rates, heating and cooling-degree days, mitigation and adaptation. Global and regional climate models, PCIC (Pacific Climate Impacts Consortium) and IPCC (Intergovermental Panel on Climate Change), climate change predictions of precip and temperature for southwestern BC, specific examples for greater Vancouver & greater Victoria.
A'	**B'**	**C**	**D**				
				8	**Topic 03. Global Distribution of Precipitation**		
					Subject Content:		
		X			a.	Precipitation microphysics & hydrometeors	
							Phases of water, warm-cloud & cold-cloud microphysics, cloud condensation nuclei, types of nucleation, collision/collection/aggregation of hydrometeors, the Wegener-Bergeron-Findeisen process, and the role of hydrometeor fall speed and air temperature. Graupel, virga, and freezing rain.
		X			b.	Precipitation intensity classification	
							Rainfall intensity classifications with weather map symbols and METAR codes, intensity-duration-frequency (IDF) curve intro (See LG4f for more details), snowfall classification vs visibility, blizzard definition, terms for snow-producing events, impacts on energy sector.

X						c.	Global circulation & precipitation patterns	
								Intro to the general circulation. Smaller-scale near-surface circulations, including trade winds, the Intertropical Convergence Zone (ITCZ), cyclones and anticyclones, subtropical and polar highs, and subpolar lows. Upper-tropospheric circulations, including the Hadley cell, jet streams, and Rossby waves. The global distribution of moisture and precipitation.
X						d.	Seasonal monsoons	
								Continential-scale warming and cooling, hypsometric and hydrostatic equations, ideal gas law, thermal circulations, thermal lows and highs, monsoon circulations, regional monsoon circulations (in W. Canada and other parts of the world), superposition of scales of motion.
X						e.	Extratropical cyclones - Part 1: Overview of formation, location & decay	
								Extratropical cyclone intro, formation, evolution, cyclogenesis, cyclolysis, baroclinic zones, tracks & propagation, tropical vs. extratropical cyclones. Vorticity, relative and absolute, vorticity advection, thermal wind.
		X				f.	Precipitation instruments	
								History of precip gauges, modern gauges (cylinder, tipping bucket, optical, acoustic, distrometers, snowfall measurement, snow densities, (measuring stick, snow pillow, snow cores & weighting, gamma-rays, weighing plates), motivation for precip measurements, snow water equivalent (SWE), examples from BC Hydro.
X						g.	Remote sensing of precipitation	
								Remote sensing intro, satellite orbital mechanics, geostationary vs. polar orbiting satellites, satellite imagery (vis, IR, wv), weather satellites, satellite interpretation of cyclones and fronts. Radar principles and history, bands (S and C bands), scanning methods, radar reflectivity, bright band, rainfall rate (Z-R relationships), Doppler radar, polarmetric radar, hydrometeor classification algorithms, radarsat, replacement of Canadian C-band with S-band radars.
	X					h.	Weather map analysis	
								Intro to weather map analysis, coordinated universal time (UTC), standardized weather reports (METAR, SPECI), station plot model, glyphs, weather maps, isopleth names, weather map feature symbols, frontal symbols, key upper-atmospheric charts, (3-D nature of weather), interpreting computer-analyzed weather maps. Appendices: time-sequence examples of surface and upper air charts, how to read METARS, details on weather-map symbols.
A'	**B'**	**C**	**D**			**Topic 04. Synoptic & Mesoscale Precip. Patterns and Variations**		
				8		**Subject Content:**		
	X					a.	Extratropical Cyclones - Part 2: Structure and Evolution	
								Extratropical cyclone structure and evolution (continued from Learning Goal 3e), stacking and tilting, warm-air conveyor belts and pre-frontal jets, lee cyclogenesis, cold lows and their effects on W. Canada.
		X				b.	Warm Front vs. Cold Front Rain	
								Intro to surface fronts (cold and warm), cold front precip., warm front precip., vertical cross section, jet streams and thermal wind, background information on potential temperature and adiabatic lifting of air parcels, occluded fronts (warm and cold front occlusions), troughs of warm air aloft (TROWAL), bent-back fronts and sting jets.
	X					c.	Atmospheric rivers	
								Atmospheric rivers: introduction, description & definition, impacts. Pre-frontal jets, "Pineapple Express" and "Tropical Punch" events, integrated water vapour transport (IVT), total precipitable water (TPW), forecasting atmospheric rivers.
		X				d.	Thunderstorm Precipitation	
								Intro to thunderstorms, description of thunderstorms and their impacts. Supercell thunderstorms, thunderstorm life cycle, global lightning density, North American tornado frequency, thunderstorm/severe weather forecasting, stability indices for thunderstorm forecasting.
			X			e.	Tropical-cyclones, hurricanes, typhoons	
								Intro to tropical cyclones, tropical cyclone structure, intensity, and geographic distribution, Saffir-Simpson tropical cyclone intensity scale, life cycle, conditions necessary for tropical cyclone formation, extratropical transition. Impacts on the energy sector, tropical cyclones in the global circulation.
		X				f.	Intensity, duration, frequency (IDF) statistics	
								Intensity-Duration-Frequency (IDF) curve description, annual exceedance probability (AEP), IDF examples, modelling IDF curves with mathematical equations, plot examples, IDF interpretation, data sources.
	X					g.	Probable Max Precip (PMP), Prob. Max Flood (PMF)	
								Probable maximum precipitation (PMP), probable maximum flood (PMF), methods of PMP estimation.
		X				h.	Precip. hazards to hydroelectric generation	
								Introduction to precipitation hazards (other than direct floods), including landslides, debris flows, and mud flows. Historical examples, dam safety agencies, landslide and debris flow videos.
A'	**B'**	**C**	**D**			**Topic 05. Topographic Effects & Precipitation Forecasting**		
				8		**Subject Content:**		
		X				a.	Orographic precipitation enhancement	
								Introduction to orographic precipitation, rain shadows, how orographic precipitation and rain shadows influence the climatology of some regions, orographic precipitation mechanisms.
			X			b.	Weather modification	
								Intro to weather modification, cloud seeding to enhance precipitation, cloud condensation nuclei (CCN), hail suppression, seeding agents, fog dispersal, controversy, currently active weather modification programs.
	X					c.	Numerical Weather Prediction (NWP) - part 1. Overview of NWP steps	
								Introduction to numerical weather prediction (NWP), model initialization, data assimilation, primitive equations, numerical computation and prediction. Model domains, model parameterizations, output products and formats, governing equations, operational NWP centers, statistical post-processing. Appendix A-Governing Equations. Appendix B- NWP Forecast Centres, Appendix C- NWP output examples.
		X				d.	Statistical post-processing - part 1. Types of Errors. Perfect prog, MOS, Kalman filtering	
								Intro to post-processing NWP forecasts, forecast refinement, systematic & random errors, perfect prog method (PPM), model output statistics (MOS), Kalman filtering (KF), updateable MOS, secondary weather variables, additive (bias) vs. multiplicative (degree of mass balance) corrections.
	X					e.	Ensemble & probabilistic forecasts - part 1. Method, motivation, utility	

							Intro to ensemble and probablistic forecasts, ensemble forecasting, ensemble averages, spaghetti plots, probabilistic forecasts, sharpness and reliability, North American Ensemble Forecast System (NAEFS).
	X				f.	Watershed models & hydrographs	
							Watershed models, hydrographs, terminology associated with hydrographs (discharge, rising limb, peak flow, falling limb, basin lag time). Hydrological watershed model types (process simulation, data-driven, hybrid). Equations associated with process simulation models. Choice of hydrologic models, models currently in use: UBCWM, WATFLOOD, HBC-EC, FEWS, VIC, SLURP, NWM. Hydrologic streamflow model errors.
X					g.	Re-analysis datasets	
							Intro to reanalysis datasets, production of reanalysis datasets through data assimilation. Currently available reanalysis datasets (CFSR, ERA5, JRA-55, MERRA-2, NOAA-20CRv3), websites for reanalysis data access.
X					h.	PRISM modeling	
							Parameter-elevation Regressions on Independent Slopes Model (PRISM) intro, motivation & development of PRISM, digital elevation model, abilities and utility in complex and coastal terrain, usage in climate maps, hypsometric curve, examples of PRISM graphics.
A'	**B'**	**C**	**D**				
						Theme: **Wind Power Meteorology**	
Case-Study Modules							
A. Weather hazard to wind turbine							
	B. Wind-farm siting						
		C. Selling wind power					
			D. Other issues				
						Topic 06. Large-scale Wind Patterns	
				9		**Subject Content:**	
	X				a.	Intro to wind turbines	
							Wind turbine basics, introduction to wind power in Canada, map and list of wind farms in BC, turbine size and height, power production, new planned wind farms, need for transmission lines, turbine heights vs. ABL depth, winds and weather for wind turbines.
X					b.	Atmospheric forces	
							Newton's 2nd Law. A list of horizontal forces and their associated equations, including pressure-gradient force, Coriolis force, turbulent drag, advection, and centrifugal forces. Determining forces from weather maps, applications.
X					c.	Winds	
							Conceptual winds, including geostrophic, gradient & boundary layer winds, their associated equations and the limitations of each conceptual wind. Newton's 1st Law (inertia), approach to geostrophy, estimating winds from weather maps.
		X			d.	Global & monsoon winds	
							The global circulation and associated global wind patterns, monsoon winds, bad & good places for wind power, global circulation nomenclature.
X					e.	Down-mixing of jet-stream winds	
							Review of jet streams, including polar and subtropical jet stream winds, and why jet stream winds are important for wind power. Mechanisms that mix jet stream winds downward, including fronts, deep convection & mountain waves. Rossby waves, ridges and troughs, meridional and zonal flow, airmasses. Aside: layers of the atmosphere
X					f.	Highs, lows, fronts & sting jets	
							Scales of motion, wind shifts during cyclone and anticyclone passage, veering vs. backing winds, wind speeds in highs vs. lows, winds at fronts, bent-back fronts & sting jets, windstorm conceptual model.
			X		g.	Synoptic-scale windstorms	
							Landfalling cyclones & storm tracks in the Pacific Northwest, cyclogenesis, cyclone bomb, Wolf Read's case studies, weakening of cyclones upon landfall (cyclolysis). Aside: wind barbs
X					h.	Thunderstorm winds - part 1: gust fronts	
							Intro to thunderstorm winds, intro to mesocyclones and supercells, downbursts and microbursts, outflow winds from downbursts, Doppler radar velocity signatures for downbursts and tornadoes. Gust fronts, gust front propagation and associated equations, formation of haboobs (sand storms) and arc clouds along gust fronts.
X					i.	Thunderstorm winds - part 2: derechos & tornadoes	
							Mesoscale convective systems, rear-inflow jets and bow echoes, straight-line winds, derechos, case study of Aug 2020 US Midwest derecho, tornadoes, Enhanced-Fujita scale for tornadoes, maps of tornado frequency in the US and Canada, forecasting thunderstorms and their hazards. Aside: photos and movies of derecho destruction
A	**B**	**C**	**D**			**Topic 07. Turbulent Boundary Layer**	
				10		**Subject Content:**	
X					a.	Descriptive overview	
							Intro to atmospheric boundary layer (ABL) structure and depth, potential temperature & its profile, air parcels and adiabatic lapse rate, diurnal variations of the ABL in fair weather, surface layer, capping inversion and entrainment zone, seasonal variations of the ABL in fair weather, synoptic variations.
X					b.	Soundings & thermo diagrams	
							Environmental soundings (observed and forecast), sample soundings, significant and mandatory levels, buoyancy, virtual temperature, thermodynamic processes & adiabats (dry and moist adiabats), dry and moist adiabatic lapse rates, thermo diagrams (types; focus on Skew-T), how to use, where to get.
X					c.	Static & dynamic stability	
							Flow stability, stability classifications (stable, neutral, unstable). Reynolds stability and the Reynolds number, static stability & the apex method, thermals in an unstable boundary layer, Brunt-Vaisala frequency in a stable boundary layer, dynamic stability, Richardson number, intro to Kelvin-Helmholtz (KH) waves.
			X		d.	Turbulence kinetic energy & convection	

								Intro to turbulence, mean & turbulent parts of wind, dissipative nature of turbulence variance & standard deviation of turbulence, turbulent kinetic energy (TKE), how statistics can be interpreted as physical concepts, advection of TKE, rate of buoyant TKE production/consumption. Mechanical generation of turbulence from wind shear, flux Richardson number, covariances & fluxes, free & forced convection, isotropic turbulence, KH waves, Pasquill-Gifford turbulence types, Reynolds stress, friction velocity, K-theory, LES, DNS.
X					e.	Boundary-layer winds		
								Typical diurnal (24 hour) ABL wind-profile evolution, geostrophic wind, subgeostrophic wind, surface layer, convective mixed layer, stable boundary layer, neutral boundary layer, boundary layer wind, similarity theory, empirical methods, nocturnal jet, inertial oscillation, supergeostrophic winds, intro to the radix layer, Deardorff velocity scale, buoyancy velocity scale, turbulent transport velocity, turbulent drag force for different static stabilities, wind shear, wind barbs, introduction to hodographs, plotting winds on hodographs.
			X		f.	Similarity-theory winds		
								Surface layer (SL), constant flux layer, similarity theory, turbulent drag, stress, friction velocity, roughness length, drag coefficient, aerodynamic roughness length, logarithmic wind profile in a statically neutral SL, displacement distance, canopy effects. Log-linear wind profile for statically stable surface layers, Obukhov length, radix layer profile for unstable SL, Deardorff velocity, difficulties with surface layer similarity theory. Appendix A: Graphic comparing molecular vs. turbulent stress magnitude in the boundary layer Appendix B: Example of how to use trial and error to manually find surface-layer parameters when there is a significant displacement distance because of a dense forest canopy.
			X		g.	Power-law, NWP & turbine-average winds		
								Power-law wind profile, comparison of logarithmic wind profile formulas, more info on aerodynamic roughness length, alternatives using numerical weather prediction and machine learning/artificial neural networks(ANN), calculating average windspeed at a wind turbine disk.
			X		h.	Low-level jet		
								Low-level jets, nocturnal jets, daily cycle of winds, LLJ nose or core, LLJ frequency, dimensions, duration, andcauses, classification of LLJ's. Inertial oscillations, ageostrophic winds, supergeostrophic winds, baroclinicity over sloping terrain, LLJ effects on wind turbines. Appendix A: Derivation of the inertial-oscillation equations
	X				i.	Large-eddy simulation		
								Microscale motions, turbulence in the ambient ABL, discrete Fourier transform (DFT), forward and inverse DFT, Nyquist frequency, turbulence spectrum, spectral energy, numerical simulation of different scales of motion, "CFL" Courant requirement for numerical stability, large eddy simulation. Asides: Lewis Fry Richardson and the Atmospheric Grey Zone
	X				j.	Turbine wakes & internal boundary layers		
								Internal boundary layers (IBL), thermal internal boundary layers (TIBL), change in roughness and IBL creation, change in surface heat flux and TIBL creation, turbine wakes, wind recovery downwind of turbine wakes.
A	**B**	**C**	**D**		**Topic 08. Orographic & Local Winds**			
				9	**Subject Content:**			
		X			a.	Measuring wind with anemometers & Doppler lidar		
								Importance of accurate wind measurements for wind turbines, MET towers, conventional in-situ wind sensors(wind vanes/anemometers), remote sensors/Doppler lidar, traditional wind sensors on wind-turbine nacelles, Doppler lidars mounted on turbine nacelles.
		X			b.	Wind variability, frequency and wind roses		
								Wind variability, wind-speed frequency distributions, relative frequency, return period, the Weibull distribution for discrete and continuous distribution functions, the gamma function, wind roses for measuring wind direction, importance of wind direction measurements.
	X				c.	Mountain waves, wakes & Froude number		
								Open channel hydraulics, wave speeds, Froude number, subcritical, critical, and supercritical flow, conservation of air mass, hydraulic jump, mountain waves, lenticular clouds, Froude number for mountain waves.
	X				d.	Wind acceleration & turbine wakes over ridges		
								Flow regimes over hills, mountain wake turbulence, cavity, definitions for wind speedup over hills, experiments to measure wind speedup, turbine wakes near ridges, Kármán vortex streets.
	X				e.	Bernoulli's equation		
								Streamlines, streaklines, and trajectories, stationary and nonstationary flow, principles of Bernoulli's equation, Bernoulli's equation for isothermal and adiabatic processes with compressible flow, applications of Bernoulli's equation, solving for dynamic effects and stagnation pressure, the Venturi effect. Asides: Solved example using Bernoulli's equation for a hydraulic jump, solved example of Bernoulli's equation for a wind turbine, solved example using Bernoulli's equation with shaft work, derivation of Bernouilli's equation.
	X				f.	Downslope windstorms: Foehn/chinook, bora winds		
								Bora winds, Foehn (chinook) winds, three Foehn mechanisms, isentropes and isentropic surfaces, downslope windstorms, downslope windstorm case studies. Asides: Prof. Stull vs. downslope windstorms, a solved example for Bora winds, a solved example for "wet" Foehn winds.
	X				g.	Gap winds		
								Gap-wind and outflow wind basics, case study examples, short and long gap winds, wind farms near mountain gaps, coastally trapped low-level (barrier) jets, Rossby radius of deformation and internal Rossby radius of deformation. Aside: YouTube videos about the wind farms at the Columbia River Gorge.
	X				h.	Anabatic, katabatic, mountain, valley & sea-breeze winds		
								Thermals, cross-valley circulations, anabatic and katabatic winds, along-valley winds and along-valley circulations. Sea breeze characteristics, dynamics, and evolution, land breezes, interaction of synoptic and sea-breeze winds, effects of complex coastlines on sea breezes, wind power from sea breezes, wind power from katabatic winds. Asides: Morning glory- a rare event associated with some sea breezes, derivation of anabatic winds.
	X				i.	Mapping wind-power potential		
								Using NWP to map wind resources, wind atlases, Global Wind Atlas, other wind atlases.
A	**B**	**C**	**D**		**Topic 09. Wind Power Forecasting**			

				11		**Subject Content:**	
		X			a.	Numerical Weather Prediction - part 2. Grid cells, time steps, and finite differences	
							Approximate solutions to the equations of motions, dynamics, physics, and numerics, parameterizations, models, grid points, finite difference methods, numerical errors and numerical instability, CFL criterion, example of a NWP forecast of winds.
		X			b.	Numerical Weather Prediction - part 3. Details about NWP procedure.	
							Moore's law and Amdahl's law, steps of the NWP process, compromises and trade-offs necessary to make a forecast on time, the need for balanced mass and flow fields, data assimilation methods (optimum interpolation and variational data assimilation), running the NWP model, and post-processing, including statistical bias corrections (MOS vs PPM), linear regression vs. Kalman filtering, calculation of secondary variables, and producing graphical output.
		X			c.	Ensemble & probabilistic forecasts- part 2. Chaos theory, ensemble forecasts, ensemble average.	
							Forecast errors (systematic and random), ensemble forecasts, ensemble average, spaghetti diagrams, probabilistic forecasts, reliability and calibration, North American Ensemble Forecast System (NAEFS).
		X			d.	Forecast skill and verification methods	
							Intro to forecast verification, forecast skill, forecast verification for continous variables, spin-up of NWP models, forecast verification for binary or categorical variables, forecast verification for probabilistic variables, issues and applications, decision making models, decision making case study. Appendix: Samples of Verification Metrics.
		X			e.	Power curve: idealized & Betz limit	
							Derivation of the power equation, turbine effect on wind speed and pressure, Betz limit for turbine efficiency, power curve, cut-in and cut-out wind speeds, feathering, feathering examples.
		X			f.	Wind-farm averaged power curve & annual energy production	
							Expected value, expected value calculation basics, using relative frequency, wind-turbine expected power and annual energy production concepts and calculation, wind-farm expected annual energy production concepts and calculation.
			X		g.	Statistical post-processing & machine learning - part 2	
							Intro to post-processing, statistical post-processing of wind speed, mean bias correction, linear regression, Kalman filtering, degree-of-mass-balance recursive bias correction, artificial neural networks, wind power computations.
			X		h.	Dispatchability & markets	
							Dispatchability, wind-plus-storage systems, power purchase agreements, independent power producers, markets and energy trading, spot market and futures market, renewable energy certificates, renewable portfolio standards. Aside: Case-study example in Australia
			X		i.	Threats & hazards to wind turbines	
							Thunderstorms, lightning, hail, sand storms (haboobs), leading edge erosion, strong winds and wind-ramp events, bores. Impacts of heavy rain, tornadoes, turbulence, ice storms, bird strikes, and bird and bug nests on wind turbines.
			X		j.	Concerns & stakeholders	
							Environmental assessment process for wind turbines, environmental assessments in Canada, environmental assessments in British Columbia, community engagement when planning and developing wind farms, stakeholders (BC Hydro, land owners, First Nations), wind farm concerns(noise, shadow flicker, bird and bat strikes), false claims.
		X			k.	Climate change impacts on wind power	
							Intro to the impact of climate change on wind power, how climate uncertainty causes energy uncertainty, climate change and the large-scale circulation, downscaling, natural variability, other aspects of climate change and wind energy.
A	**B**	**C**	**D**				
						Theme: **Solar Power Meteorology**	
Case-Study Modules							
A. Radiation reaching home PV panel							
	B. PV farm site selection						
		C. Attenuation by clouds					
			D. Other issues				
						Topic 10. Incoming Solar Energy	
				6		**Subject Content:**	
X					a.	Radiation fundamentals	
							Intro to radiation fundamentals, energy, flux, irradiance, solar spectrum, blackbody irradiation, Planck's law, inverse square law, Stefan-Boltzmann law. Aside: solved examples of spectral irradiance at different wavelengths using Planck's law and the inverse square law
X					b.	Variations in total solar irradiance	
							Solar irradiance, solar constant, Earth-Sun distance, celestial coordinate system, solar declination angle.
X					c.	Daily cycle of local solar elevation angle	
							Definition of insolation, position of the sun, hour angle, equation of time, solar zenith, elevation, and azimuth angles. Insolation on a horizontal surface, incident angle for incoming solar radiation on a tilted plane such as a solar panel. Aside: solved example for calculating hour angle
X					d.	Atmospheric attenuation	
							Intro to atmospheric attenuation, concept of atmospheric interaction, atmospheric scattering, absorption, and reflection, Rayleigh and Mie scattering, direct, diffuse, and reflected radiation. Global horizontal irradiance (GHI), albedo, Rayleigh atmosphere, turbidity, beam radiation on a tilted plane, diffuse radiation on a tilted plane, diffuse fraction models, ground-reflected irradiance on a tilted plane, additional factors. Aside: solved example for calculating turbidity
	X				e.	Local affects & shading from obstacles	
							Intro to shading in the context of solar power, optimal collector placement using solar angles to avoid shading, soiling. Aside: solved example of calculating optimal spacing for rows of solar panels in a PV system.
X					f.	Radiation sensors	
							Some radiation instrumentation theory, common radiation sensors (pyranometer, heliometer, diffusometer). Aside: Campbell-Stokes sunshine recorder

A	B	C	D				
					Topic 11. Solar Power Generation		
				9	**Subject Content:**		
X					a.	Photovoltaic solar panel types & efficiencies	
							Intro to photovoltaics, the photovoltaic effect, PV cells, modules, arrays, and systems. Optimum tilt angle, PV module types (silicon, thin film, other technologies). Aside: solved example of calculating the maximum power that a PV module can provide.
	X				b.	Photovoltaic solar panel performance	
							The "IV curve", maximum power point (MPP) values and peak power, temperature coefficient and module temperature, other weather variables affecting PV module power output (wind, hail, snow, sandstorms). Aside: solved example of calculating PV module temperature
			X		c.	Solar collectors & concentrators	
							Intro to solar collectors/solar thermal systems, flat-plate collectors, evacuated-tube collectors, concentrators, concentration ratio. Concentrating solar power (CSP) plants, parabolic trough, fresnel, solar dish, solar tower, CSP electricity generation and storage.
	X				d.	Utility-scale components	
							Introduction, direct and alternating current, inverters (central inverters, string inverters, and microinverters), transformers. Asides: real and apparent power, cable length for inverters.
	X				e.	Utility-scale dispatchability	
							Siting and scaling of utility-scale solar PV systems, estimating power and energy yield, optical losses before absorption, temperature-induced power losses, power loss fraction. Output from a module, output from whole system, data sources, calculating energy output: irradiance vs irradiation, making utility-scale solar dispatchable. Asides: working example of calculating the power loss fraction and the amount of power lost due to module temperature, working example of calculating the total energy produced by a solar power plant.
	X				f.	Utility-scale storm hazards	
							Intro to extreme weather events that can damage solar panels, how solar panels can be damaged, mitigation/prevention of damage, transmission line damage.
		X			g.	Home-scale components & siting issues	
							Introduction, off-grid vs. grid-connected, components of residential solar, site selection, installation requirements, load requirements, financial requirements. Aside: foggy mornings in the Gangetic Plains in northern India/southern Nepal, and resulting slight westward tilt of solar panels.
		X			h.	Home-scale energy storage & battery technology	
							Energy storage, battery technologies, including lead acid batteries, lithium ion batteries, and other technologies.
		X			i.	Home-scale energy: incentives and system size	
							Incentives for residential solar, installation subsidies and net metering, payback period, system sizing calculations, examples of system sizing calculations. Asides: calculating payback period, solved example of battery bank calculations, solved example of calculating number of modules and total rooftop area
A	B	C	D				
					Topic 12. Clouds		
				10	**Subject Content:**		
		X			a.	Cloud types	
							Intro to how clouds affect solar energy, cloud classification, cumuliform, stratiform, and special clouds, clouds and synoptics, cloud coverage and obscurations.
			X		b.	Cloud microphysics	
							Cloud physics- the Kohler curve, supersaturation of air, environmental supersaturation, lifting condensation level (LCL), excess water vapor mixing ratio, heterogenous nucleation, cloud condensation nuclei (CCN), curvature effect, solute effect, Kohler curve, droplet supersaturation, summarized conclusions.
		X			c.	Satellite observations of clouds	
							Clouds and satellite imagery, revisiting visible & infrared satellite imagery, identifying cloud types from satellite imagery, summarized conclusions.
		X			d.	Clouds vs. insolation 1: cloud cover	
							Introduction to the effect of cloud cover on insolation, solar obscuration, patterns of how cloud cover affects irradiance. Aside: refresher on how clouds interact with solar radiation, summarized conclusions.
		X			e.	Clouds vs. insolation 2: stratiform clouds	
							Transmittance and optical depth, the effect of stratiform clouds on insolation (cirrus, altocumulus, altostratus, stratus, nimbostratus), summarized conclusions.
		X			f.	Clouds vs. insolation 3: cumiliform clouds	
							The effect of cumuliform clouds on insolation (stratocumulus, cumulus, cumulonimbus), summarized conclusions.
			X		g.	Terrain effects on clouds	
							Introduction to dynamically driven and thermally driven terrain effects, wind-driven orographic clouds, rain shadow, other orographic clouds, local buoyancy-driven orographic clouds.
		X			h.	Fog	
							Fog basics, dewpoint temperature, isobaric cooling, types of fog: radiation fog, advection fog, upslope fog, steam fog, and precipitation fog. Calculation of radiation fog onset time and depth, evaporative cooling, and valley fogs vs. solar farms. Asides: supersaturation from a dew-point perspective, solved example of calculating radiation fog onset time and depth
	X				i.	Global distribution maps of cloudiness and solar energy potential	
							Global distribution of clouds, including effects of the global circulation, monsoons, oceans, and mountains, and a global map of average cloud cover. Global distribution of solar energy, summarized conclusions.
		X			j.	Numerical weather prediction of clouds	
							Intro to NWP of clouds, grid cells and resolvable scale, interpreting NWP cloud forecasts, including darkness vs. altitude and darkness indices. Case study of NWP cloud-darkness forecasts, ensemble cloud-cover forecasts, meteograms.
A	B	C	D				
					Topic 13. Human Factors		
				6	**Subject Content:**		

	X						a.	Air pollution sources & dispersion
								Intro to causes of air pollution, types of pollutants, particulate matter, spread of pollutants, dry vs. wet deposition, forecasting pollutants, air-quality forecast models, aerosols.
	X						b.	Effects of pollutants on solar radiation
								Attenuation of solar radiation, effects of pollutant concentrations, Angstrom's turbidity formula, effects of PV materials, soiling. Asides: transmittance and optical depth, solved example of calculating aerosol transmittance for different particle size distributions α and various turbidities β.
			X				c.	Wildfire smoke effects
								Fire weather, including winds, temperature, and moisture. Atmospheric dispersion of forest fire smoke, clouds generated by wildfire smoke plumes, smoke impacts on air quality and insolation, wildfires caused by humans. Aside: fire basics
			X				d.	Anthropogenic clouds
								Intro to anthropogenic clouds, classification and formation of anthropogenic clouds, WMO naming conventions, high-altitude homogenitus (jet contrails), low-altitude homogenitus (fumulus), smog, potential impacts of anthropogenic clouds on solar power.
		X					e.	Climate-change impacts on solar power
								Background, changes in surface solar radiation due to cloud cover and aerosol changes, changes in temperature, other influences on solar PV, summarized conclusions.
	X						f.	Concerns and downsides of solar energy technology
								Drawbacks of solar energy, including land use (direct and indirect), water use for cleaning panels, mining and manufacturing of finite resources for solar energy, greenhouse gas (GHG) emissions due to solar energy manufacturing, and degradation of PV modules. Recycling of modules after the end of lifespan. Aside: Units of g CO_2 eq/kWh explained
A	**B**	**C**	**D**					
								Theme: **Synthesis of Renewable Energy Concepts**
Case-Study Modules								
A. Interplay of various clean energies								
	B. Energy Future							
		C. ePortfolio Project						
								Topic 14. Simultaneous Storm Effects on Different Renewable Energies
						8		**Subject Content:**
X							a.	Electric grid connections of hydro, wind and solar sources
								Intro to grid connection, hydro connection to grid, windfarm connection to grid, solar connection to grid (PV and CSP).
X							b.	Relative values of renewable vs. clean vs. green energy - Part 2
								Levelized cost of electricity, cost trends for clean energy, environmental and social costs, including technology-specific negative side-effects of renewables.
X							c.	Reliability, dispatchability, interchangeability
								Reliability of electric power infrastructure, North American regional reliability councils, case studies of high-impact power grid failures due to weather, dispatchable power generation, base load power plants, spinning reserve and load following, load matching, peak matching, and frequency regulation, interchanges.
X							d.	Generation: interplay between wind, solar & hydro power during cyclone passage
								How an extratropical cyclone affects clean power generation, simulated example of co-located hydro, wind, and solar power generation, power production simulations, examples of hybrid (co-located) clean energy projects.
X							e.	Load: interplay between weather and psychology
								Heat and behaviour, cold weather and human behaviour, sustainable energy transition and human relations, green power tarrifs, intro to smart meters.
X							f.	Transmission: interplay between ampacity and weather
								Introduction to and definition of ampacity, dynamic thermal rating, annealing, strategies to manage renewable energy transmission to avoid annealing.
X							g.	Energy trading: seasonal, short term, & spot market
								Introduction to electricity markets (also known as power exchanges), power purchase agreements, independent system operators (ISO's) and regional transmission organizations (RTO's). History, deregulation of electricity markets, wholesale and retail electricity markets, renewable energy market and renewable energy trading. Canadian electricity regulation, including background and regulatory authorities, US electricity market deregulation. Terminology, including feed-in tariff, green tariff, net metering, renewable energy certificates (REC)'s, and weather derivatives. Aside: 2000-2001 California electricity crisis.
X							h.	Climate change vs. relative values of hydro, wind, and solar power
								Shifts in relative timing of energy production and demand, heating and cooling degree days, impacts of increased temperatures directly on infrastructure and power generation, ease of adaptation, summarized conclusions.
A	**B**	**C**						**Topic 15. Population Growth and Our Energy Future**
						10		**Subject Content:**
	X						a.	Other renewables: tidal, wave, biomass, geothermal
								Introduction to other renewables, bioenergy including thermal, thermochemical, and biochemical bioenergy, geothermal, including background and geothermal in Canada, and ocean power, including thermal energy, mechanical/tidal energy, salinity gradient energy, and ocean power in Canada.
	X						b.	Questionable clean energies: nuclear, natural-gas thermal
								Definitions of different forms of grid-scale energy sources(renewable, clean energy, etc.), nuclear power, fission and fusion, pros and cons of nuclear power production, nuclear power around the world, including Canada. Natural gas, including simple cycle gas-turbine and combined cycle gas-turbine plants, pros and cons of natural gas, liquified natural gas (LNG).
	X						c.	Home-scale generation
								Reasons for home electricity generation, home generation options, home-scale solar panels, solar shingles, residential wind power, hybrid systems, micro-hydro power.
	X						d.	Grid-scale and home-scale energy storage

										Intro to energy storage, energy storage for intermittent clean energy, advantages and disadvantages of grid-scale energy storage, grid scale battery storage, other existing grid energy storage methods, home scale battery storage.
	X					e.	Smart grid & smart meters			
										Intro to power outages/blackouts, definition of a smart grid, smart meters, benefits of smart meter networks, benefits of a smart transmission grid, automated weather stations and weather forecasts, the 2003 North American power blackout. Aside: types of power outages (transient faults, brownouts, blackouts, rolling blackouts).
	X					f.	Increasing demand: transportation, home electronics, air conditioning			
										Intro to increasing global electricity demand, electric demand from transportation and electrification of transportation (electric cars, etc.), electric demand from home appliances and electronics, electric demand from home appliances and electronics, electric demand from air conditioning, and conclusions, including impacts of COVID-19 on global energy demand and future growth. Aside: coldest and warmest provinces/states in Canada and the US.
	X					g.	Conservation and population growth			
										Electricity conservation measures, including the Energy Star program, global population growth projections, summarized conclusions.
	X					h.	Vulnerability of the electric supply			
										Intro to the vulnerability of the power system. List of electric power grid risks, including earthquakes, physical attacks, squirrels, cyber attacks, operations errors, tsunami, weather events, space weather, volcanic events, floods, wildfires, and drought.
	X					i.	Energy shortages			
										Intro to energy crises. Historical energy crises, including the 1973 oil crisis, the 1979 oil crisis, the 1990 oil shock, the 2000-2001 California energy crisis, the 2000's energy crisis, the 2008 global financial crisis energy glut, the 2008 Central Asia energy crisis, and the 2019 California power shutdown.
	X					j.	Our energy future			
										Our future, prospects for renewable energy, you as a citizen scientist.
A	**B**	**C**								
						ePortfolio Project: Annual Energy Potential from Renewable Energy Sources				
					1		Instructions:			
		X					1. Get the instructor's approval for the town or other site for this project			
		X					2. Create a report or blog as a Canvas ePortfolio for:			
		X						a. Annual precipitation at that site		
		X						b. Annual wind-power potential at that site		
		X						c. Annual solar-power potential at that site		
		X						d. Overall conclusions / recommendations		
			Total count of LGs =	125						
							Other topics that might be added in future terms:			
								2-hydro		Backdoor upslope precipitation in the prairies
										Convergence lines: regional and local
										Probability of precipitation (PoP) vs. Forecasts of areal coverage