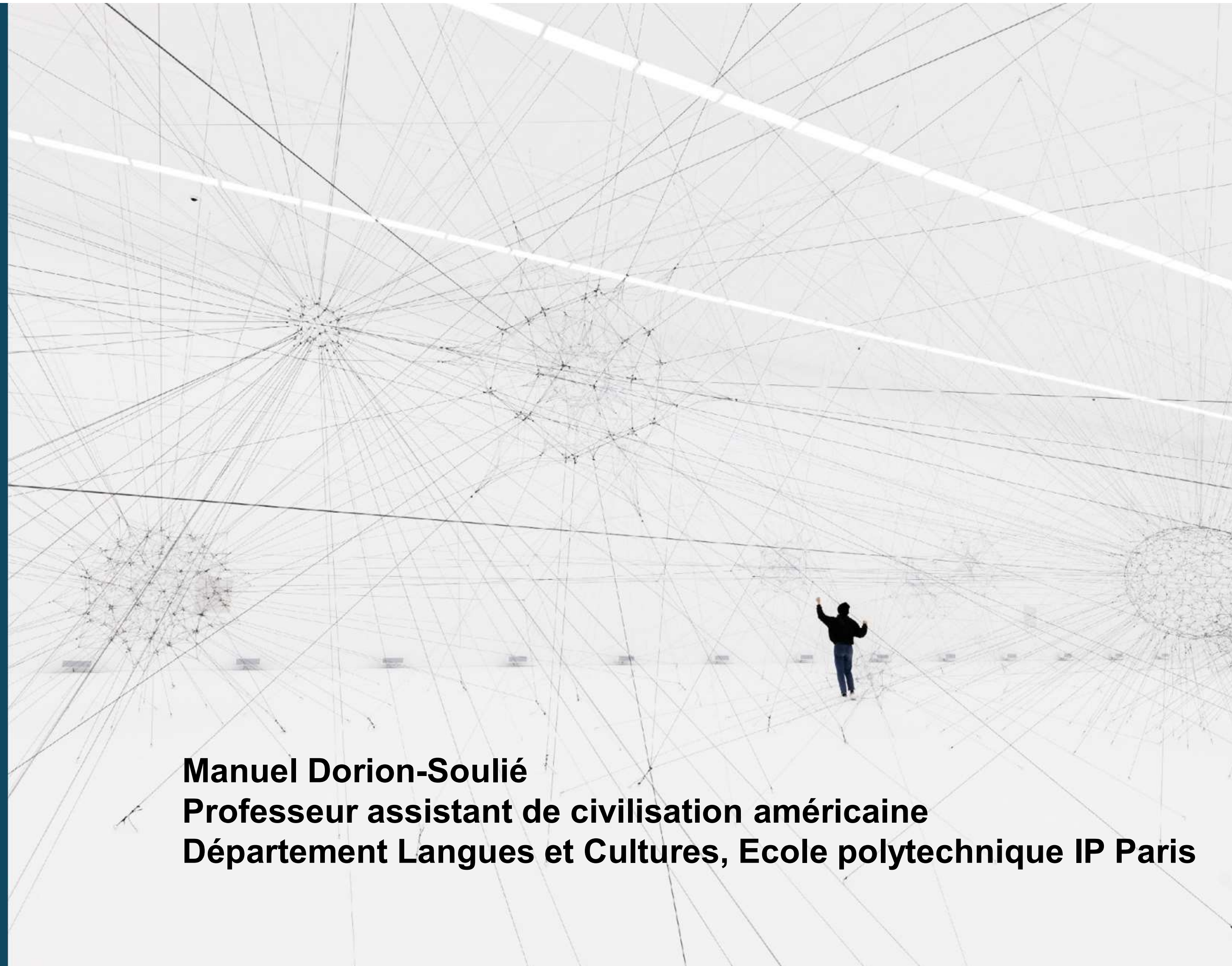
Engineering Sustainability

S’ingénier pour durer

Ecole polytechnique

“When we try to pick out anything by itself we find that it is bound fast by a thousand invisible cords that cannot be broken, to everything in the universe.”

(John Muir)



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Algo-r(h)i(y)thms, 2024. Installation view from *Complementarities* at Red Brick Art Museum, Beijing, China, 2024. Curated by Yan Shijie. Photography by Studio Tomás Saraceno. Courtesy the artist, Red Brick Art Museum, Tanya Bonakdar Gallery, New York/Los Angeles and neugerriemschneider, Berlin.

Engineering Sustainability

- **550 élèves (cours obligatoire)**
- **15 Amphis x 90 minutes**
- **10 TD (2 Modules x 5 séances, groupes de 24) x 90 minutes**
- **7 départments: Biologie, Chimie, Economie, Langues et Cultures, MIE, Mécanique, Physique**
- **24 professeurs (8 dans l'équipe pédagogique)**

Edition 2025

Aug. 25	The WALC (Walk Around and Look at the Campus)	
	Lecture series	Modules
Aug. 26	Introduction	Module 1, week 1
Sept. 02	Cycles and pollution (G. Nocton)	Module 1, week 2
Sept. 09	Climate (R. Plougonven)	Module 1, week 3
Sept. 16	Biodiversity (M. Mouchet)	Module 1, week 4
Sept. 23	How did we get here? (M. Dorion-Soulié)	Module 1, week 5
Sept. 30	WE? Unsustainable inequality (C. Guivarch)	Module 2, week 1
Oct. 07	Intermezzo – planetary boundaries	Module 2, week 2
Oct. 14	Energy (D. Suchet)	Module 2, week 3
Oct. 21	Mitigation policies (C. Guivarch)	Module 2, week 4
Holidays		
Nov. 4	Governance and organizations (P. Acosta)	Module 2, week 5
Exams P1		
Nov. 19	Conclusion + preparing final case study	
Nov. 20	Final case study	
Dec. 11	Final exam	

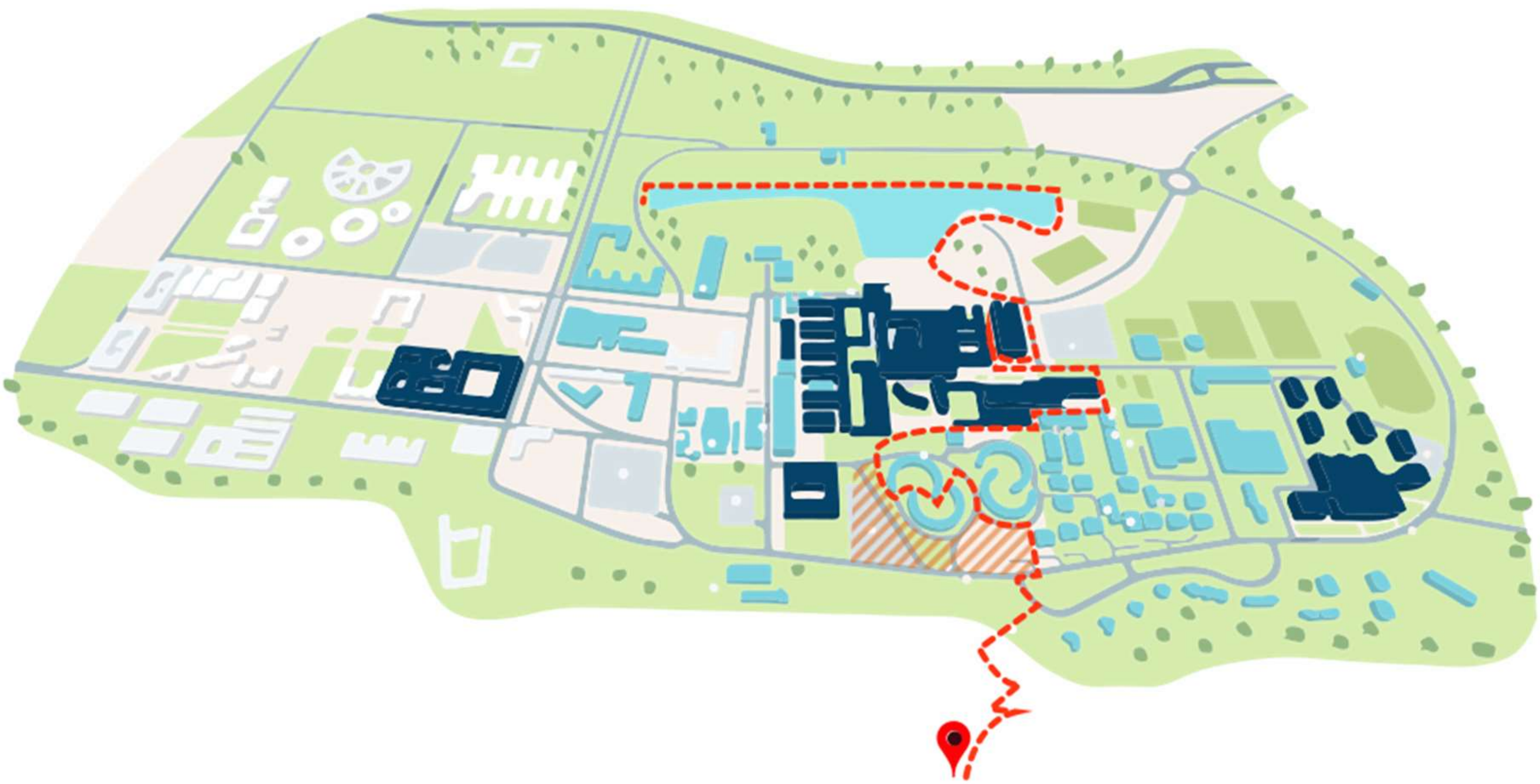
Lectures: Tuesdays
1:15 – 2:45pm

Modules:
Tuesdays 3:00-4:30pm
and 5:00-6:30pm

For students interested, possibility to volunteer to co-organize a side-event for the UNFCCC COP (organized by Patricia Crifo)

Conclusion lecture 8:00-9:30am
Work on final case study: 9:45am – 12:45pm
Final case study restitutions: 9:00-10:30am and 10:45-12:15am

Séance 1: Promenade sonore



TRANSPORTS
Rear-view mirrors, blindspots, and roads ahead

The module proposes a deep-dive into the dynamics of the transport sector in France. We will study the (re)construction of transport networks after 1945, the inequalities in mobility trends, as well as forward-looking scenarios for the future of transports.
The transport system is chosen as a prime example of a complex system with significant environmental footprints and major economic and social impacts. The module's objective is to challenge students to consider the future of the transport system and devise strategies to address the climate emergency, while being able to consider other environmental constraints, as well as the technological, economic, social and political forces that shape the transport system.

Content

The module is organized around the triptych of players –the private sector, government and households - sometimes presented as the 'triangle of inaction', to be turned into the 'triangle of action and transformations'. The aim of each session is to provide an understanding of the key orders of magnitude, the important dynamics and the concepts that need to be borne in mind. The sessions are built around data analysis, critical reading of documents, the use of analytical tools (e.g. calculating the carbon footprint of vehicles, socio-economic analysis of public policies, game theory, statistical data analysis) and historical vignettes that provide historical depth to the analysis.

Learning objectives

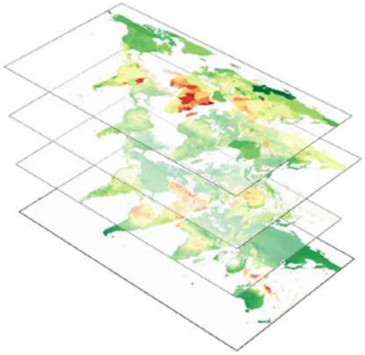
- Understanding the historical context and dynamics that shaped the transport systems in France
- Understanding current situation of transport systems in France, and differentiated situations depending on territories and households
- Knowing how to analyze statistical socioeconomic data, and characterize evolutions and variability
- Mobilizing analytical methods and concepts (carbon footprint calculation, socioeconomic assessment of public policies, game theory, externalities)
- Using tools to analyze the internal consistency of forward-looking scenarios (eg Kaya decompositions), and knowing their limits

Terms of evaluation

Preparing a short document (in small groups) to present the chosen strategy to decarbonize the transport system, justified in the light of the points covered in the module. Participation during the sessions will also be included in the final grade.

CLIMATE PROJECTIONS
From climate modelling to risks for humans and adaptation options

The module aims at exploring certainties and uncertainties on climate change and putting some substance behind the statement "*every fraction of degree of global warming matters*". It will give tools to analyze **climate projections** and **socioeconomic data**. It will explore the questions of who is, and who will be, exposed to climate change impacts, and how vulnerability may be defined, measured, and reduced with **adaptation** measures. The whole module will use the case of **heatwaves** to conduct the analyses, and focus on the urban heat island effect.



Content

- Manipulate climate projections and population dataset with Jupyter notebooks (statistical and spatial analysis in Python).
- Analyze the evolution of heatwaves in a changing climate.
- Define and measure exposure and vulnerability to climate change impacts.
- Read and understand a research article, a systematic review and IPCC Assessment Report Figures.
- Explore the mechanisms explaining the urban heat island effect, and adaptation options.

Learning objectives

- Know how climate projections are constructed with climate models.
- Know how some population and socioeconomic datasets are built.
- Define and distinguish projection and predictions, risk and uncertainty.
- Articulate different spatial and temporal scales.
- Use statistical and spatial analysis tools to study climate and socioeconomic data.
- Use concepts and indicators to measure climate risks and vulnerability.
- Understand how climate risks may evolve in the future depending on actions.
- Know how adaptation options can be assessed.
- Understand how scientific research is conducted, assessed and communicated.

Terms of evaluation

A written note documenting climate risks and proposing adaptation options for a chosen territory (in small groups) and participation during the sessions.

ENERGY TECHNOLOGIES

From thermodynamics to society

Energy technologies are technical objects enabling the capture, conversion and utilisation of energy. They are crucial to address the environmental, social and economic challenges of sustainability. The laws of thermodynamics help explain their operation and the estimation of their ultimate efficiencies.

However, the ability of energy technologies to tackle current issues does not depend only on their technical performances, but also on their potential to transform industries, markets, and society. It is therefore essential to understand the diffusion process of such innovations, and what unexpected effects or adverse consequences they trigger.

This interdisciplinary module, combining physics and management studies, offers a hands-on experience of the crucial dynamics driving today's energy transition.

Content

- Derive ultimate conversion efficiencies (Carnot, Curzon Ahlborn) from basic principles
- Material efficiency, resource exhaustion and Hubbert's peak theory
- Rebound effect (Jevon's paradox)
- From idea to market, the non-linear path of innovation diffusion
- Focus on the end of pipe: user acceptance and influence

Learning objectives

- Know how to apply the first and second law to derive conversion efficiencies
- Know usual efficiency indicators and their domains of relevance
- Know toy models for material resource exhaustion and their limitations
- Understand contributions to the rebound effect and how to quantify them
- Treat, plot, fit and interpret numerical data
- Identify the multiple levels of innovation diffusion
- Analyze sources of resistance, adoption and improvement to technological innovation

Terms of evaluation

Presentation, participation, involvement

LIFE CYCLE ANALYSIS (LCA) AND CIRCULAR ECONOMY

The module explores life cycle analysis principles, eco-design, and circular economy. We will reflect on life cycle analysis as a foundational assessment for designing sustainable products and developing circular economy strategies.
By doing so, we critically assess the potentials and limitations of life cycle analysis, eco-design, and circular economy in shaping sustainable products.

Contents

- Conduct a life cycle analysis of an everyday product subject to environmental issues with specialized software (SimaPro)
- Assessing the design of a product using the eco-design wheel
- Analysis of a case study of industry strategies for circularity
- Conduct a life cycle analysis for a given product (chosen by students in the agribalyse database, https://agribalyse.ademe.fr)
- Propose eco-design and circular strategies for the given product (chosen by students)

Learning objectives

- Understand the principles of life cycle analysis to use them as a decision-making tool
- Know how to conduct a basic life cycle analysis
- Understand and apply the principles of eco-design
- Understand the link between life cycle analysis, eco-design, and an organizational strategy
- Analyze a circular economy strategy
- Develop a circular economy strategy

Terms of evaluation

Individual quiz + final presentation of a study-case using the principles developed in class (small groups).

Cas final:
3 heures en classe pour préparer, groupes de 4, Restitution orale

Format 2024 :

Que signifiera "bien vivre" en 2050? Choissez un secteur (transports, alimentation, habitat…) et un territoire.

→ jugé trop court par les élèves (ce qui a conduit à des stratégies de survol du sujet, peu intéressant/engageant pour les groupes ne présentant pas; intervenants mis en difficulté car loin de leur expertise pour beaucoup et car le choix laissé aux élèves implique que l'on ne peut pas préparer

Format 2025 :

« Débat » sur des questions du type : Légiférer pour limiter chaque individu à 4 vols long-courrier dans leur vie est-il à même de constituer une réponse pertinente aux enjeux de soutenabilité ?

- Objectifs, et grille d'évaluation :
  - Capacité à penser « systémique » (i) aborder comment la solution envisagée a des implications pour différentes limites planétaires, différents « systèmes », différents secteurs d'activités ou territoires ? (ii) quels liens avec les questions d'inégalités ? (iii)… ;
  - Capacité à penser comment une solution s'intègre dans un contexte historique, économique, social, et à aborder les obstacles ou leviers de mise en œuvre

Examen final: QCM

- 89 questions (mais + en fait…), 3 heures
- La moyenne de la promo est de 14: max 17.7, min 8.2
- 41 A (16-20), 383 B (13-16), 124 C (10-13) et 7 D (plus 3 absents à l'exam).
- Note finale: QCM (50%) ; Présentations (en petits groupes) et participation dans les deux modules choisis (2 * 20%) et dans le cas d'étude final (10%)

On s'intéresse à un projet de rénovation d'une maison individuelle de 100m². La consommation annuelle d'énergie finale pour le bâtiment est de 6 000 kWh/an pour le chauffage et de 1 500 kWh/an pour l'eau chaude sanitaire et l'éclairage. Le chauffage est assuré par une chaudière gaz (efficacité 90%) ; l'eau chaude sanitaire et l'éclairage sont électriques.

On envisage différentes options de rénovation énergétique :

- Option 1 : On remplace la chaudière gaz par un poêle à bûches avec une efficacité de 60%.
- Option 2 : On remplace la chaudière gaz par une pompe à chaleur avec un coefficient de performance de 2.2.
- Option 3 : On améliore l'isolation de la maison et on réduit la consommation de chauffage de 25%.
- Option 4 : On installe 5m² des panneaux solaires photovoltaïques, qui fournissent une puissance moyenne sur l'année de 20 W/m².

16) Laquelle de ces options permet d'atteindre la plus basse consommation **d'énergie primaire** ? (1 point)

A. Option 1. B. Option 2. C. Option 3. D. Option 4.

17) Laquelle de ces options permet d'atteindre la plus basse consommation **d'énergie primaire non renouvelable** ? (1 point)

A. Option 1. B. Option 2. C. Option 3. D. Option 4.

18) Laquelle de ces options permet d'atteindre les plus basses **émissions de gaz à effet de serre** ? (1 point)

A. Option 1. B. Option 2. C. Option 3. D. Option 4.

19) Laquelle de ces options permet d'atteindre la plus basse consommation **d'énergie finale** ? (1 point)

A. Option 1. B. Option 2. C. Option 3. D. Option 4.

Retours d’expériences: les élèves

- 23 délégués, 3 réunions d’échanges, questionnaire en ligne standard (admin), sondage complémentaire par le Binet NeXt… articles du journal étudiant…
- Un cours supplémentaire dans un trimestre chargé: faible présence en amphis MAIS très forte présence en TD → charge horaire VS charge de travail à la maison
- Format amphi (en général) critiqué: captation vidéo disponible sur moodle rend présence superflue?
- Un format non-conventionnel qui déroute → mieux expliquer le contrat pédagogique, mieux expliquer le fil rouge, simplifier le cadre, mieux faire le lien entre les différentes briques

Amphis et Modules 2025

Where are we ?
Planetary boundaries

How did we get here ?
Anthropocene

How do we get out of here?
S'ingénier pour durer

1 Intro
2 Cycles and pollution
3 Climate change
4 Biodiversity
5 History of mass-consumption society
6 Unsustainable inequalities
7 Intermezzo
8 Energy
9 Climate change mitigation policies
10 Governance and the private sector
11 Conclusion

Module 1
Module 2
Case study

ENERGY TECHNOLOGIES
From thermodynamics to society

LIFE CYCLE ANALYSIS AND CIRCULAR ECONOMY

CLIMATE PROJECTIONS
From climate modelling to risks for humans and adaptation options

TRANSPORTS
Rear-view mirrors, blindspots, and roads ahead

Retours d’expérience: la direction

Retours d’expériences: les collègues et les départements

- Ajout à la charge horaire des élèves = ajout au planning = problèmes de créneaux
- Difficulté à faire reconnaitre les heures consacrées au cours: départements ou direction?
- Absence de soutien type scolarité, gestion des vacataires etc.
- Contribution à un cours « hors département »: qui va la valoriser?