ENE425 Sustainable Energy and App Development

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Contents

Chapter 4

Sustainable energy. Global Energy Transformation. A road map to 2050

This chapter is based on the report entitled "Global Energy Transformation. A road map to 2050" (IREMA, 2019b). The report focuses its analysis on **two pathways** for the global energy system:

- **Reference Case:** This scenario considers current and planned policies of countries. It includes commitments made in Nationally Determined Contributions and other planned targets. It presents a perspective based on governments' current projections and energy plans.
- **REmap Case:** This scenario includes the deployment of low-carbon technologies, based largely on renewable energy and energy efficiency, to generate a transformation of the global energy system that limits the rise in global temperature to well below 2 degrees Celsius above pre-industrial levels. The scenario is focused on energy-related carbon dioxide emissions, which make up around two-thirds of global greenhouse gas emissions.

The **Reference Case** is an energy pathway set by current and planned policies. The **REmap Case** is a cleaner climate-resilient pathway based largely on more ambitious, yet achievable, uptake of renewable energy and energy efficiency measures, which limits the rise in global temperature to well below 2 degrees and closer to 1.5 degrees above pre-industrial levels and is aligned within the envelope of scenarios presented in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C.

For more information about the REmap case and the data used in that case visit (link).

The analysis presented in this chapter (IREMA, 2018) is based in the **E3ME model**. E3ME is a macro-econometric model designed to assess global policy challenges. It is the most advanced econometric model in the world and is widely used for policy assessment, forecasting and research purposes. The model is owned and maintained by Cambridge Econometrics. For more information about E3ME model visit (link).

For more details and the **manual** of the model visit (link).

4.1 Highlights

1. **Electrification with renewable power** can start to reduce energy-related carbon dioxide ($CO2$) emissions immediately and substantially. The pairing has also other positive effects:

- Renewable energy is becoming cheaper than fossil fuel-based alternatives.
- It contributes to lower local air pollution and increases health benefits.
- It has a positive socio-economic benefits
- It will be a key enabler to build a connected and digitalised economy and society.

Electrification, when paired with renewables, goes hand-in-hand with energy efficiency, resulting in lower overall energy demand.

2. By 2050 **electricity** could become the central energy carrier, growing from a 20% share of final consumption to an almost 50% share.

   - Renewable power will be able to provide the bulk of global power demand (86%).
   - The primary drivers for this increased electricity demand would be over 1 billion electric vehicles, increased use of electricity for heat and the emergence of renewable hydrogen.
   - Overall, renewable energy would supply two-thirds of final energy.

3. **Total investment** in the energy system would need to reach USD 110 trillion by 2050, or around 2% of average annual gross domestic product (GDP) over the period.

4. **Annual energy-related CO^2 emissions** in the REmap Case decline 70% below today's level. An estimated 75% of this reduction can be achieved through renewable energy and electrification technologies; if energy efficiency is included, then this share rises to over 90%.

   The report shows that emissions would need to be reduced by around 3.5% per year from now until 2050, with continued reductions after that time. Energy-related emissions would need to peak in 2020 and decline thereafter.

5. Any energy transition roadmap will interact with the evolution of the socio-economic system upon which it is deployed, producing a series of outcomes that can be understood as the **socio-economic footprint**.

   - By 2050, GDP increases by 2.5%, relative to the Reference Case.
   - The overall relative improvement over the Reference Case across the three dimensions of the welfare indicator (economic, social and environmental) is 17%, strongly driven by the improvements in health and environment.

6. **Climate damages**: For the end of the century (year 2100) global GDP reductions are estimated at around 20% for a 2°C global warming and 35% for a 5°C global warming are reported (Burke et al, 2018). In terms of GDP, by 2050, the relative improvement over the Reference Case increases from 2.5% to 5.3% when climate damages are factored into the macroeconomic analysis.

4.2 Main findings

1. **The transformation of the global energy system needs to accelerate substantially** to meet the objectives of the Paris Agreement. Those objectives are to keep the rise in average global temperatures "well below" 2 degrees Celsius (2°C) and ideally to limit warming to 1.5°C in the present century, compared to pre-industrial levels.

2. **Renewable energy supply**, increased electrification of energy services, and energy efficiency can deliver more than 90% of needed reductions to energy-related CO2 emissions. Renewable energy and electrification alone deliver 75% of emission reductions.

- Electricity would progressively become the central energy carrier, growing from a 20% share of final consumption to an almost 50% share by 2050.
- Renewable power would be able to provide the bulk of global power demand (86%) economically. As a result, gross electricity consumption would more than double.

3. Changes in the energy system have impacts throughout the **economy**.
   - By year 2050, the REmap energy transition brings about relative improvements of GDP and whole-economy employment of 2.5% and 0.2% respectively.
   - In cumulative terms from 2019 to 2050 the GDP gains of the REmap Case over the Reference Case add up to 99 USD trillion.
   - The global welfare indicator measuring the improvement of REmap over the Reference Case reaches in 2050 a value of 17
4. Changes in the energy system have impacts in **employment**.
   - Across the world economy, overall employment increases between 2018 and 2050 for both the Reference and REmap cases, with CAGRi of 0.45% and 0.46% respectively.
   - The REmap Case produces more jobs than the Reference Case, with relative gains peaking around 2035 and remaining around 0.2% until 2050.
5. **Climate damages** will have a significant impact on the socio-economic footprint.
   - Macroeconomic performance under both the Reference and REmap cases is significantly impacted by climate damages, leading to a global GDP reduction of 15.5% and 13.2%, respectively, by 2050.
   - Despite this high impact, the global economy would still experience a significant growth due to the high growth rates achieved without climate damages under the considered socio-economic context: The CAGR between 2019 and 2050 with climate damages would be 1.8% and 2.0% for the Reference and REmap cases respectively, down from the 2.4% and 2.5%without climate damages.

4.3 A pathway for the transformation of the global energy landscape

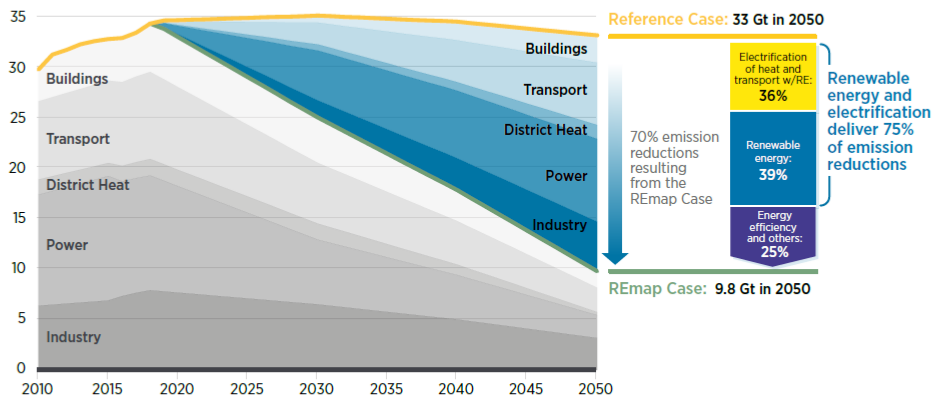
4.3.1 Energy-related CO2 emissions

Based on a carbon budget from the latest Intergovernmental Panel on Climate Change (IPCC) special report on the impacts of global warming of 1.5°C (IPCC, 2018), the Reference Case in this report shows that the global energy-related CO2 budget will run out at the latest by 2030 (based on the IPCC assessment of a 50% confidence level for 1.5°C). To set the world on a path way towards meeting the aims of the Paris Agreement, energy-related CO2 emissions would need to be scaled back by at least an additional 400 gigatonnes (Gt) by 2050 compared to the Reference Case; in other words, **annual emissions would need to be reduced by around** 3.5% **per year from now until 2050 and continue afterwards**.

Annual energy-related CO2 emissions under current and planned policies – the Reference Case – are expected to remain flat, at 33 Gt CO2 per year in 2050, but must be reduced by 70% to bring temperature rise to the well-below 2°C climate goal – as in the REmap Case. **Electrification**, **renewable energy** and **energy efficiency** measures provide over 90% of the reductions required by 2050. Renewable power and electrification of heat and transport alone reduce emissions by 75% (figure 4.1).

For more information about the Intergovernmental Panel on Climate Change (IPCC), visit: link.

Figure 4.1: Annual energy-related CO^2 emissions



Source: IRENA (2019)

In 2010 about 9 Giga-tons of Carbon (GtC) were emitted from burning fossil fuels as 33 Giga-tons of CO2 gas.

How much is 9 Giga-ton? 9 billion tons or 9.000.000.000.000.000 grams. 9 Giga-tons is the weight of about 132 billion people. The amount of carbon we are putting into the atmosphere each year is equal to 20 times the weight of the current world population.

For more information about **annual CO2 emissions** data visit:

- International Energy Agency (link).
- Global Monitoring Laboratory (link).

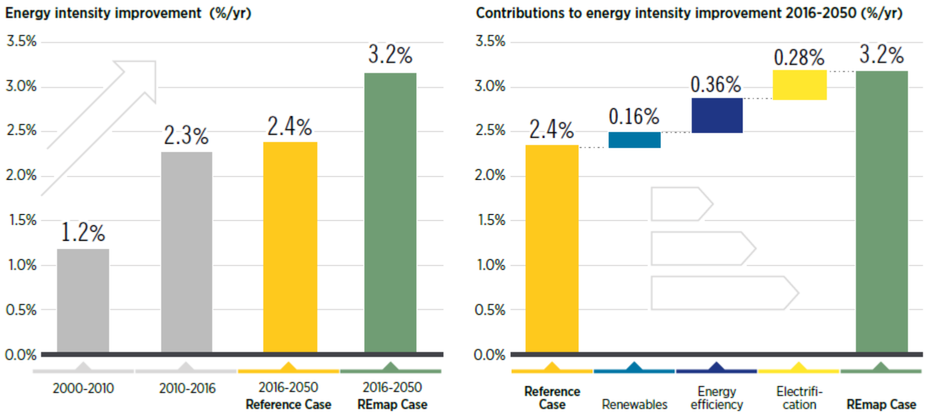
For more information about the **carbon cycle** and the **greenhouse effect** visit Global Monitoring Laboratory (link).

4.3.2 Energy intensity

The **energy intensity** improvement rate would need to increase to 3.2% per year. This is higher than the improvements in recent years (2.3%) or projected in the Reference Case (2.4%) (figure 4.2). The gap between the rate in the Reference Case and what is needed in REmap can be filled through several key means:

- Scaling up solar, wind and other renewables.
- Improving energy efficiency.
- Electrifying transport and heat.
- Structural change in transport and industry.

Figure 4.2: Energy Intensity



Source: IRENA (2019b)

Energy intensity is a measure of the energy inefficiency of an economy. It is calculated as units of **energy per unit of GDP**.

- **High energy intensities** indicate a high price or cost of converting energy into GDP.
- **Low energy intensity** indicates a lower price or cost of converting energy into GDP.

High energy intensity means high industrial output as portion of GDP. Countries with low energy intensity signifies labor intensive economy.

For more information about energy intensity, visit:

- Wikipedia (link 1).
- American Energy Department (link 2).

4.3.3 An electrified future

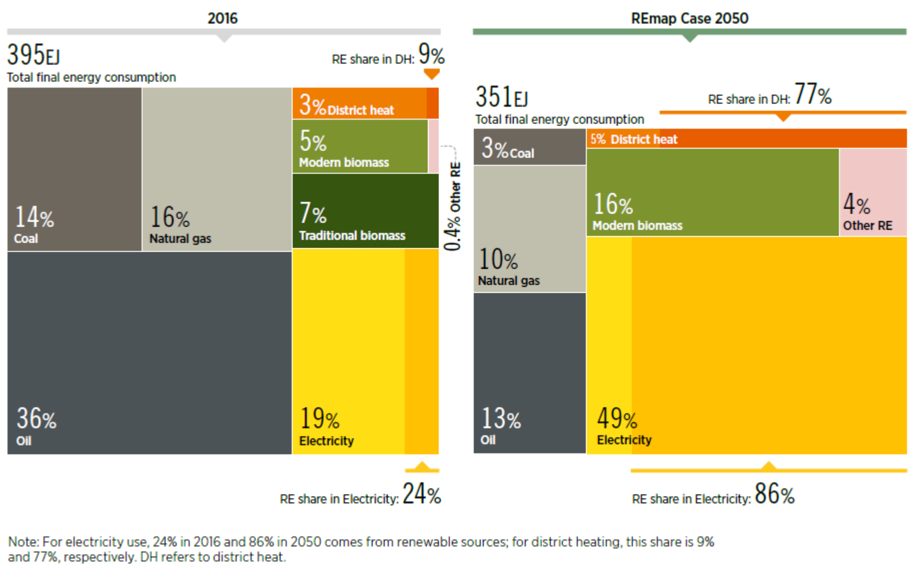
The increasingly electric energy system would transform how the power sector and demand interact. By 2050, 86% of electricity generation would be renewable, and 60% would come from solar and wind. Wind and solar PV would dominate expansion, with installed capacities of over 6 000 GW and 8500 GW, respectively, in 2050 (figure 4.3).

The share of electricity in final energy would increase from just 20% today to almost 50% by 2050 (figure 4.3). The share of electricity consumed in industry and buildings would double. In transport it would need to increase from just 1% today to over 40% by 2050.

4.3.4 The weight of renewables in electrification

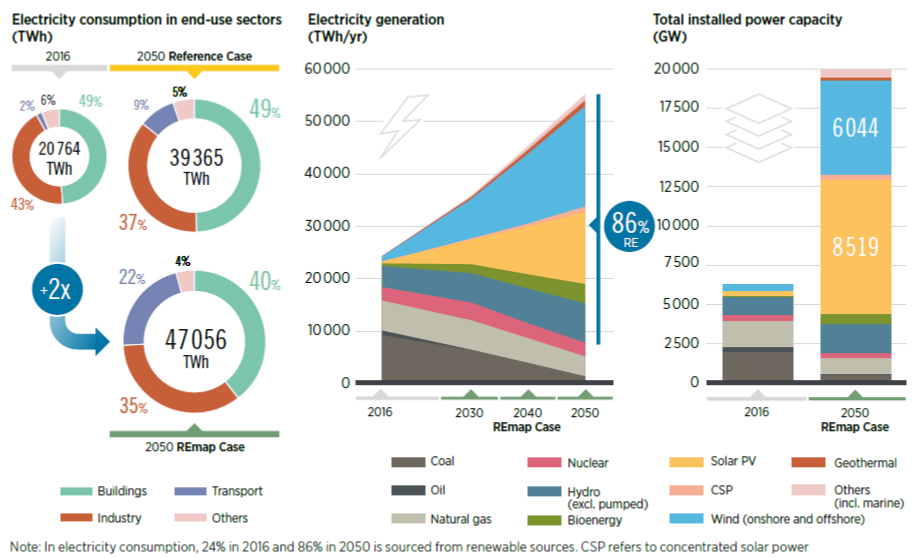
By 2050, solar power, with 8 500 GW installed capacity, and wind, with 6 000 GW, would account for three-fifths of global electricity generation. Electricity consumption in end-use sectors will more than double from today's level (figure 4.4).

Figure 4.3: Total final energy consumption breakdown by energy carrier (%)



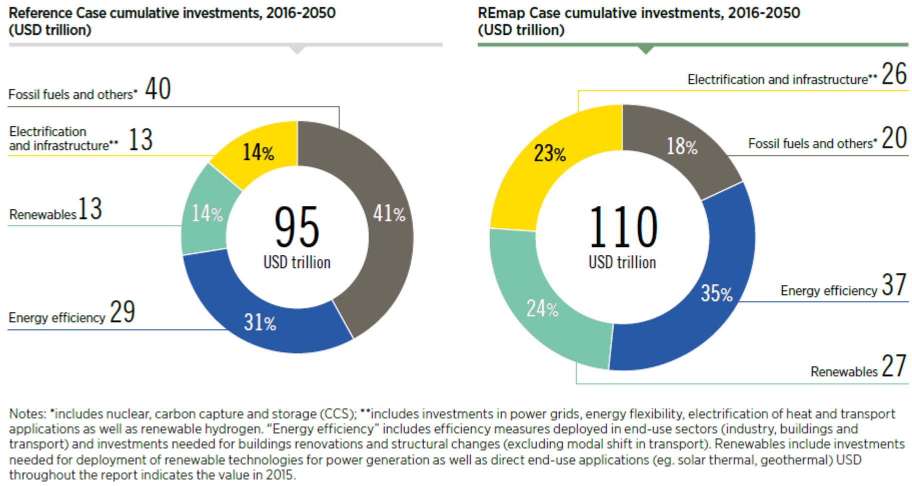
Source: IRENA (2019b)

Figure 4.4: Wind and solar dominate growth in renewable-based generation



Source: IRENA (2019b)

Figure 4.5: Investments



Source: IRENA (2019b)

4.3.5 Investments

Cumulative investments in the energy system to 2050, including infrastructure and efficiency, will total almost USD 95 trillion in the Reference Case, and would increase to USD 110 trillion in the REmap Case (figure 4.5).

Renewable power technologies are increasingly the least-cost electricity supply options available. The renewable energy market would grow quickly as costs continue to decline, as technologies improve and as innovation brings additional applications.

The REmap Case increases investments in the global energy system by USD 15 trillion, and shifts investment into electrification, renewable energy and energy efficiency technologies, which together, would make up four-fifths of the cumulative energy sector investments over the period to 2050.

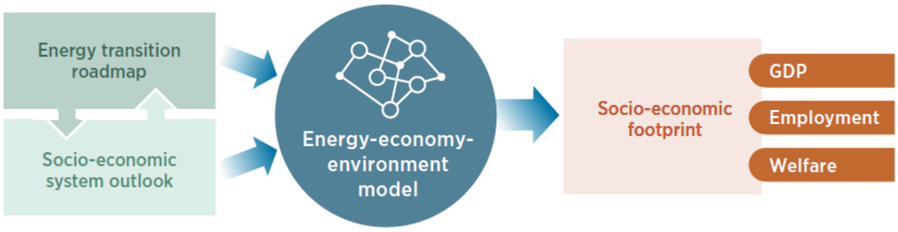
However, an energy system based heavily on renewables would be different than past systems and would require significant investments in **power grids**, complementary infrastructure and energy flexibility. In the Reference Case, investments for these would amount to USD 9 trillion. In the REmap Case, an additional USD 4 trillion would be required, for a total of USD 13 trillion.

4.4 Measuring the socio-economic footprint of the energy transition

The power and energy systems are embedded into the wider socio economic system, which in turn is embedded into the earth and its climate. In order to avoid dysfunctional outcomes, a holistic policy framework is needed to frame and support the transition (figure 4.6).

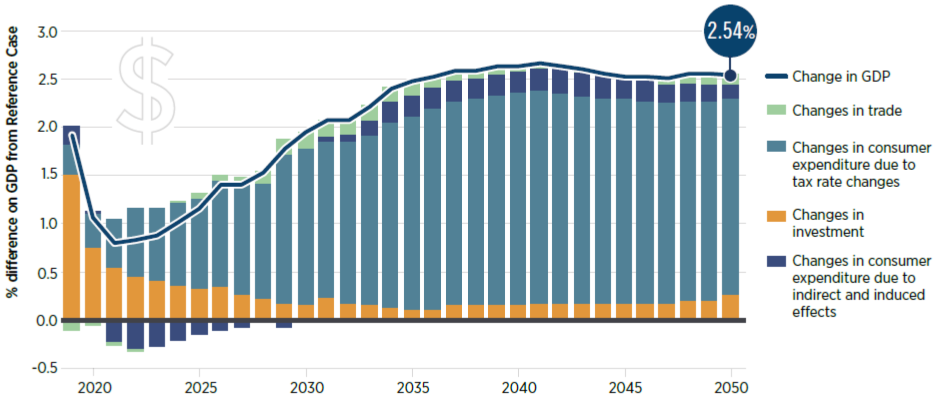
Both the energy and socio-economic systems will evolve during the transition, with multiple feedback loops between them. IRENA uses an integrated Energy-Economy-Environment model to evaluate the socio-economic footprint that results from the interactions among different combinations of the energy transition roadmap and the socio-economic outlook.

Figure 4.6: Energy transition and its socio-economic footprint



Source: IRENA (2019b)

Figure 4.7: Relative difference of global GDP between the REmap Case and the Reference Case, 2019-2050



Source: IRENA (2019b)

4.4.1 Energy-wide GDP and employment impacts

The analysis presented in this section builds on IRENA's body of work, which has focused on measuring the economics and benefits of the energy transition and on assessing renewable energy employment (IRENA, 2019a, 2018, 2017, 2016; IEA and IRENA, 2017). The analysis delves into macroeconomic variables to present the socio-economic footprint of the REmap roadmap, both at global and regional levels, as deployed within the current socio economic system.

In order to gain insights into the structural elements underpinning the socio-economic footprint, IRENA's macroeconomic analysis decomposes the outcomes in different drivers. The main macroeconomic drivers used to analyse the GDP and employment footprints include (figure 4.7):

- Investment.
- Trade.
- Tax changes.
- Indirect and induced effects.

In the short term, the net positive impact on global GDP is due mainly to a front-loaded **investment** stimulus in renewable energy generation capacity, energy efficiency, and energy system flexibility to support the transition. The overall impact of this driver gradually fades in importance as time progresses.

Gains in **consumer expenditure** due to tax rate changes become the dominant factor in the evolution of GDP between 2022 and 2050. This driver captures the impact of the changes in government income due to carbon taxes, fossil fuel phase-out, changes in fossil fuel royalties and other taxes.

The **employment** gains are expected to be less significant than for GDP because additional demand in the global economy also pushes up real wages. The additional wage volume available can be translated either as wage increases for all workers, or as an increase in the number of jobs, or a mix of both. Historical trends show that wage effects tend to dominate, leading to smaller increases in employment than GDP.

4.4.2 Climate damages and its impact on GDP

The literature suggests that very important impacts from climate change can be expected on the performance of the socio economic system both in terms of reducing global GDP and increasing inequality:

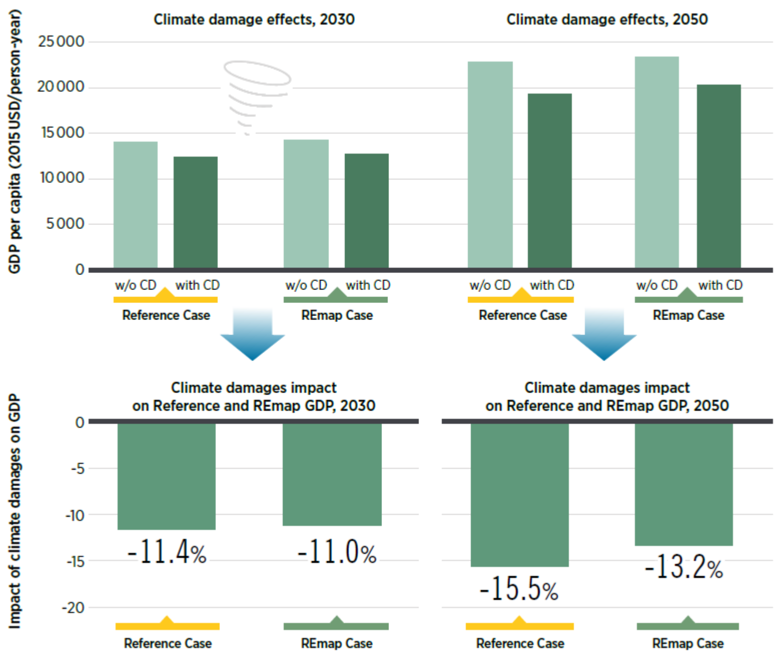
- For the end of the century (year 2100) global GDP reductions are estimated at around 20% for a 2°C global warming and 35% for a 5°C global warming are reported (Burke et al, 2018).
- Climate damages will lead to increased inequality because much higher impacts can be expected in warmer regions, which often correspond to poorer countries (Burke et al, 2015).

The upper graph in figure 4.8 presents per capita GDPs with and without climate damages. Clear green bars represent the per capita GDP without taking into account climate damages, while dark green bars represent the per capita GDP once climate damages are factored in. As it can be seen both REmap and Reference cases experience a significant reduction in GDP when climate damages are included in the macroeconomic modelling. To better understand these reductions, the lower graph in figure 4.8 presents the percentage reduction in GDP when climate damages are included, showing how important are the GDP reductions attributable to climate change.

What does the applied climate damage methodology does not include? The results obtained can be considered conservative, because there are several ways through which climate change can negatively impact the economy that are not captured by it:

- Sea level rise and increased incidence of extreme weather events (flooding, draughts, tropical cyclones, wildfires...).
- Disrupted trade and modified trade dynamics based on modified power positions, where regions with higher damages on GDP (Global South) experience losses in trade balance, and winners (Global North) use the advantageous situation to impose trade agreements.
- Social conflict effects associated to disruption and increasing inequality.
- Cross-country spillovers associated to climate change that would produce higher economic impacts (for example, supply chain interruptions/alterations, trade effects...)

Figure 4.8: Impact of climate damages on GDP results



Source: IRENA (2019b)

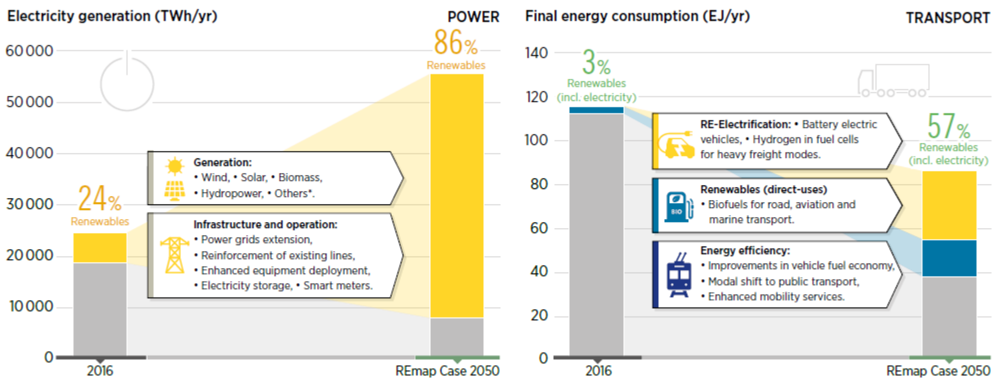
4.5 Action needed now

This chapter makes clear that an energy transition is urgently required, and that **renewable energy**, **energy efficiency** and **electrification** are the three cornerstones of that transition.

In this section, we present some of the key actions that are needed now to achieve the Paris agreement.

1. The **power sector** needs to be transformed to accommodate growing shares of variable renewables.
    - Develop power systems that provide a high level of technical **flexibility**.
    - Better **market signals** are needed to enable flexibility resources to come into play to cope with the uncertainty and variability of variable renewable energy (VRE) generation. Examples include real-time variable pricing and shorter trading intervals.
    - Power markets will need to be redesigned to enable the optimal investments for systems with high levels of VRE and enable sector coupling.
2. **Digitalisation** is a key enabler to amplify the energy transformation.
3. Accelerating the **electrification** of the transport and heating sectors is crucial for the next stage of energy transformation.
4. **Hydrogen** produced from renewable electricity could help to reduce fossil-fuel reliance.
5. **Supply chains** are key to meet growing demand for sustainable **bioenergy**.
    - **Bioenergy** must be produced in ways that are environmentally, socially and economically sustainable. There is a very large potential to produce bioenergy cost-effectively on existing farmland and grassland, without encroaching upon rainforests, and in addition to growing food requirements.

Figure 4.9: Sector level actions. Power and Transport sectors



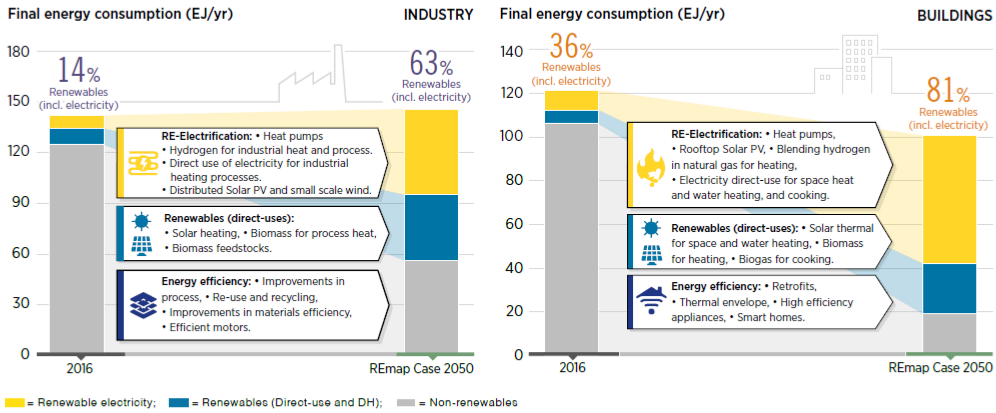
Source: IRENA (2019b)

- **Biomass-based industries** that generate ready-to-use biomass residues – such as pulp and paper, lumber and timber, and food – are fundamental in the transition.
- In sectors such as aviation, shipping and long-haul road transport, **biofuels** might be the main or only option for decarbonisation for years to come.

Actions in the power, industry, buildings and transport sectors are essential to realise the global energy transformation by 2050. Below, we present an overview of major actions at the sector level:

1. **Power (left-hand side panel, figure 4.9):**
   - Accelerate renewables capacity additions. In particular, identify and map renewable energy resources and develop a portfolio of financeable projects.
   - Plan for the power sector to accommodate increasing shares of variable renewable energy.
   - Support the deployment of distributed energy resources. In particular, incentivise energy consumers to become prosumers.
2. **Transport (right-hand side panel, figure 4.9):**
   - Reduce the energy need for transport. First, by deploying advanced digital communication technologies to reduce the transport needs (eg. teleconferencing over travelling) and to improve efficiency of transport by better utilizing the assets (eg. re-routing due to traffic). Second, by promoting mobility services, e.g., promote vehicle sharing and autonomous driving.
3. **Industry (left-hand side panel, figure 4.10):**
   - Reduce energy consumption in industries. First, by promoting actions towards circular economy (material recycling, waste management, improvements in materials efficiency and structural changes such as reusing and recycling). Second, by incentivising and adopting best available technologies (BAT) and efficiency standards.
   - Enable corporate sourcing of renewables by supporting a credible and transparent system for certification and tracking of renewable energy attributes.
   - Accelerate the deployment of low-carbon technologies in industrial process heating.

Figure 4.10: Sector level actions. Industry and Buildings sectors



Source: IRENA (2019b)

4. **Buildings (right-hand side panel, figure 4.10):**

   - Reduce energy consumption in buildings. First, by establishing and improve energy efficiency building codes and standards (incl. appliances (eg. air conditioners), lighting (eg. LED lights) and equipment (eg. efficient boilers)). Second, by adopting programmes for retrofitting/renovation including financing schemes.
   - Support and foster the deployment of distributed energy resources by removing regulatory barriers for prosumers that restrict them from taking an active role in the energy system transformation.
   - Scale up renewable share uptake in the building sector by promoting low-carbon heating technologies: heat pumps, solar heating, modern bioenergy for heating). Apply these renewable technologies for district heating.

Sector coupling refers to the idea of interconnecting (integrating) the **energy consuming sectors** - buildings (heating and cooling), transport, and industry - with the **power producing sector**. Making electricity the default form of energy in these sectors would be a step towards what is sometimes referred to as an "all-electric world."

For more information about sector coupling visit:

- Journalism for the energy transition (link 1).
- IRENA, sector coupling (link 2).

Supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer.
For more information about supply chains visit:

- Wikipedia (link 1).
- Investopedia (link 2).

4.6 Some questions to summarize the chapter

In this section, we propose some questions that could be useful to summarize the main points studied in this chapter.

1. Carbon emissions must be reduced to 10 GT per year in 2050. Which are the **three main ways to reduce carbon emissions**?

   Electrification, introduction of renewable energy and energy efficiency

2. Which are the **four sectors** where carbon emissions need to be more effective?

   Power sector, industry sector, transport sector and building sector

3. The share of electricity in the energy production will pass from 20% to 80%. Which **share of electric production will be renewable**?

   The 86% of the electricity will be produced by using renewable energy

4. Which will be the **share of electricity use by sector**?

   40% in the building sector, 33% in the industry sector, 22% in the transport sector

5. In the **power sector**, the renewable share will pass from 24% to 86%. Can you enumerate the main **sources of renewable production**?

   Solar, wind, biomass and hydropower

6. In the **transport sector**, the renewable share will pass from 3% to 57%. Can you enumerate the **main changes in that sector**?

   EV, hydrogen for heavy freight modes, biofuels for road, aviation and marine transport

7. In the **industry sector**, the renewable share will pass from 14% to 63%. Can you enumerate the **main changes in that sector**?

   Hydrogen for industrial heat and process; direct use of electricity and renewables for industrial heating processes

8. In the **building sector**, the renewable share will pass from 36% to 81%. Can you enumerate the **main changes in that sector**?

   Renewables for heating, and electricity; biogas for cooking; increase in efficiency

4.7 Questions: Competition Policy and European Green Deal

The video of the conference is in the this link. To motivate the discussion, I propose you some questions:

<u>Frans Timmermans</u>

1. Of the EU recoverage package, which proportion will be **invested** in **green energy (climate policy)** and **digitalization**?
   30% will be invested in green economy and 20% will be invested in digitalization. The rest will be invested in sectors that foster digitalization and the adoption of a green economy
2. Which are the main sectors that could be **more problematic to de-carbonize**?
   The building, the transport and the agriculture sectors
3. Which are some of the **policies** that could be implemented to green the economy?
   Price on carbon emissions, regulation predictability and long-term stability

Pedro Size Vieira

1. Which are the **four (five) main objectives** of the current Portuguese government?
   Demographic change, digitalization, inequalities, green economy and biodiversity
2. Which are the main **technologies** used to promote the electrification of the country? Which will be the **share of renewable energy** production and consumption in Portugal in the next years?
   The technologies to produce electricity will be hydroelectric, wind and solar. The share of renewables in production is the 60% and the share of renewables in consumption is 40%

Sven Giegold

1. To foster the adoption of green technologies, Sven Giegold introduces the concept of fair price. Could you explain which policies should by implemented to obtain **fair prices**?
   First, the subsidies on pollution technologies should by phased out. Second, the pollution technologies need to internalize their externalities on society
2. Which are the policies to be implemented to foster the **investments in green technologies**?
   First, state aids in critical technologies, that are still not mature to be competitive. Second, to ban the subsidies to fossil fuels, and fossil fuels infrastructure
3. Which are the policies to mitigate the **impact of digitalization on carbon emissions**?
   Digitalization should be treated as a "quasi-infrastructure" and should be taxed according with "quasi-infrastructure" taxation

Philippe Aghion

Philippe Aghion claims that **markets are not able to promote green innovation** by themselves, since firms tend to be conservative

1. Which are the main **State policies** to foster green innovation?
   Carbon taxes, carbon prices, subsidies and incentives similar to arpa-e in USA
2. Which are the **main driver in the civil society** that foster green innovation?
   The societies in which consumers demand "green products" creates the conditions for green innovations, since the firms need to compete to attract those consumers

Mechthild Wörsdörfer

1. Which are the share of **carbon emissions by sectors**?
   40% CO2 emissions in the power sector, 25% CO2 emissions in the transport sector, 20% in the industry sector, the rest in other sectors
2. Which are the **main four economy areas** to green the economy?
   First, EV sales should move from 3% nowadays to 100% in 2050. Second, the heating system need to be electrified. Third, energy intense industries (cement, steel, chemistry) need to be electrified. Fourth, the building stock need to increase its efficiency (currently, the 75% is inefficient)
3. Which are the policies to foster **green innovation**?
   The 50% of the 400 different types of technological innovations required to green the economy are still not mature to be competitive. It is necessary State aid to foster green innovation

4.8 Bibliography

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