Inevitable Policy Response - Scenario Models

Introduction:

The Inevitable Policy Response (IPR) was commissioned by the Principles for Responsible Investment (PRI) and aims to prepare institutional investors for the portfolio risks and opportunities associated with a forecast acceleration of policy responses to climate change.

Overview

The Inevitable Policy Response provides the most extensive set of open-source scenarios and underlying investor Value Drivers that are publicly available. This access enables financial institutions to assess the risks and opportunities across the major sectors impacted by climate transition. The Inevitable Policy Response has produced two climate scenarios to date:

1. **Forecast Policy Scenario (FPS)** – A fully integrated climate scenario modelling the impact of the IPR Policy Forecasts on the real economy up to 2050. The FPS is IPR's current assessment of what is expected to happen in terms of future policy developments and the subsequent impact on emissions reductions and temperature outcomes. The FPS modelling was run in both 2019 and 2021.

2. **1.5°C Required Policy Scenario (1.5°C RPS)** – A 1.5°C scenario demonstrating IPR's assessment of future policy developments required to accelerate emissions reductions and restrict a global temperature increase to a 1.5°C outcome. The 1.5°C RPS modelling was run for the first time in 2021.

Full results and Value Drivers from the 2021 scenario runs can be found here. The FPS and 1.5°C RPS scenarios are built using the same integrated energy and land use system economic analysis:

- **Energy System Modelling** – tracing detailed system effects for all emitting sectors
- **Land Use System Modelling** – tracing detailed system effects for land use sectors
- **Macroeconomics** – modelling the impacts of IPR on the overall economic system

This document provides an overview of the IPR scenario development process and the IPR economic models used for each IPR scenario.

Description of scenario development process

The scenario development process involves modelling the expected evolution of the energy and land systems, in the context of the IPR policy forecasts, in a suite of modelling tools.

The IPR policy forecasts are represented in the energy and land models in one of two ways:

- The IPR forecast carbon prices are directly entered into the model, to identify cost-effective abatement options and the resulting GHG emissions pathway.
- Specific policies, such as coal phase out or zero emissions vehicle policies are entered into the model as constraints, such as on operation of coal generators or sale of fossil fuelled vehicles.

The modelling tools used in IPR 2021 are described in more detail in Section 1. The modelling process for 2019 is described in section 2. 2021 scenarios used a new Energy and Macroeconomic model with deeper levels of granularity.

Overview of IPR economic models and their outputs in 2021

Significant increases in policy ambition from company to country level, technology advances and the impacts of Covid-19 drove the need for a new Forecast Policy Scenario (FPS).

In 2021, Vivid Economics produced an updated Forecast Policy Scenario, building on the modelling work conducted to produce the Inevitable Policy Response Forecast Policy Scenario in 2019. The models selected for the FPS in 2021 offer greater granularity and flexibility while remaining robust, transparent, reliable and replicable.

Key model changes include the introduction of the Vivid Energy System Model (VESM) and the National Institute Global Econometric Model (NiGEM) macroeconomic model. Key output changes include the discontinuation of portfolio level results in exchange for more granular Forecast Policy Scenario outputs ("Value Drivers") that will allow investors to construct their own portfolio level results.

Finally, the underlying IPR Policy Forecasts that feed into the Forecast Policy Scenario for 2021 were released separately in March 2021, in contrast to their joint release 2019. These Policy Forecasts were further updated to incorporate significant developments in policy announcements or technology that arose before 2021 FPS modelling began.

These changes have been made in order to ensure the 2021 FPS provides maximum value add for users while remaining robust, transparent and replicable.

1 Description of models used in IPR 2021 scenarios

1.1 Energy - Vivid Energy System Model (VESM)

- VESM is a global, whole energy system model that computes the least cost configuration for an energy system based on given technology projections and policy constraints. The input parameters are the technoeconomic aspects of power generating/heat/transport technologies, fuel and carbon prices, and demand for different energy carriers.
    - **Modelling environment.** VESM is built using the open-source energy Modelling System (OSeMOSYS) modelling environment. Vivid have created a model (VESM) within this system, which has been peer reviewed by energy system modellers at Imperial University. The IPR Policy Forecasts are publicly available and act as constraints on the VESM model. The VESM model can be run for others on a paid-for basis, as was the case with the TIAM model used in 2019.
    - **Linkages within the energy system.** Linked with Whole Energy System Investment Model (WeSIM) to generate realistic electricity decarbonisation pathways. (see below for more details)
    - **Linkages to land-use and broader macroeconomy.** Linked with land (MAgPIE) model and macro-economic model NiGEM to generate coherent scenarios across energy, land and economic systems. (see below for more details)
    - **Data vintage.** All data updated annually.
    - **Key Outputs.** Detailed breakdown of CO2 emissions, energy demand, technology deployment, and capital investment by sector and region.
    - **Granularity:**
        - **Geographical.** 21 world regions (12 major nations and 9 composite regions), together delivering total coverage of world economy.
        - **Temporal.** 2020-2100 with 5-year time slices. Based on this, the FPS derives annual forecasts to 2040.
        - **Sectoral.** 7 sectors (fuel production, power, hydrogen, transportation, industry, buildings, agriculture including Direct Air Capture and synthetic fuel production) with further segmentation into 34 distinct segments.
    - **Advantages:**
        - In-house ownership allowing substantial dedicated modelling resource and full transparency of modelling drivers and outcomes.
        - Annual data updates with the latest update completed immediately prior to the IPR 2021 scenario analysis.

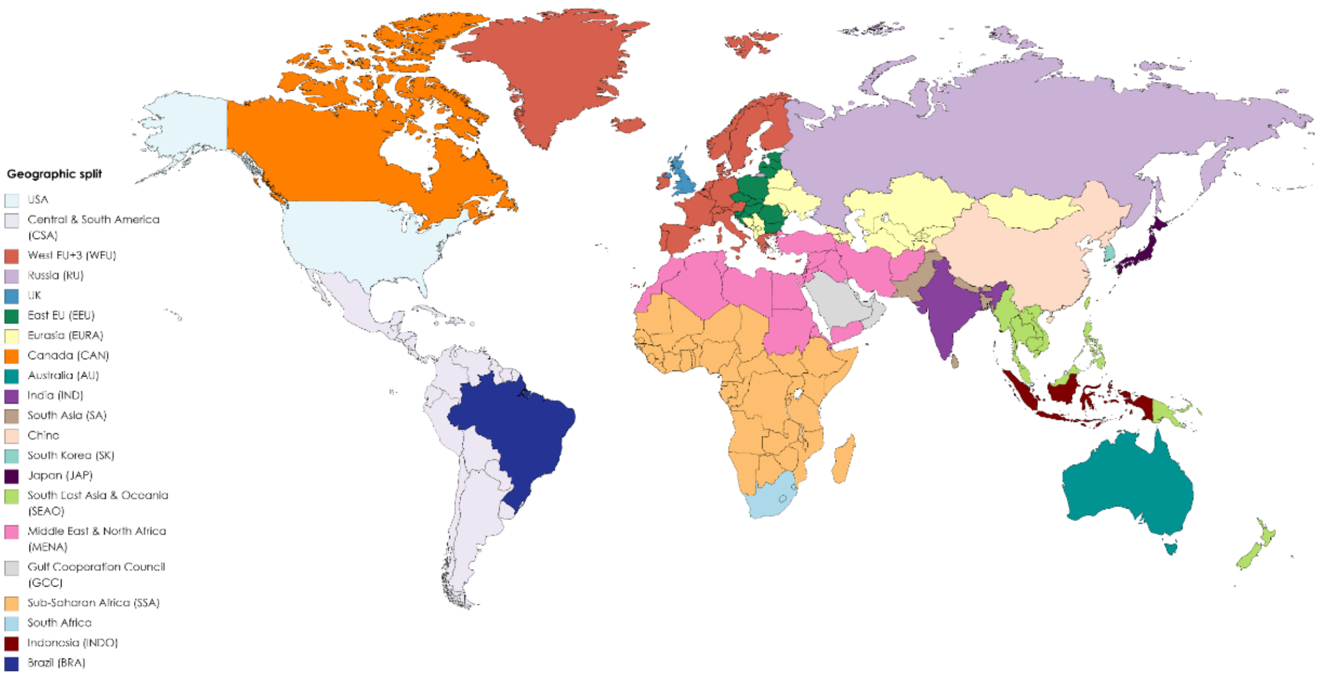
- Full specification of net zero technologies: carbon capture and storage, direct air capture, hydrogen, across all major uses.
- Linkage with WeSIM electricity model provides realistic power sector decarbonisation pathway.

Table 1 Difference from IPR 2019 model (TIAM-Grantham)

Parameter	TIAM-Grantham 2019	VESM 2021
Ownership (mode of operation)	Imperial College (outsourced)	Vivid Economics (In house)
Data vintage	Various	2021
Net zero technologies (CCS, hydrogen, direct air capture, synthetic fuels)	Limited specification	Full specification
Power sector granularity	4 periods	Hourly modelling when paired with WeSIM
Geographical coverage	15 world regions (8 major nations and 7 composite regions)	21 world regions (12 major nations and 9 composite regions)

Source: Vivid Economics

Figure 1 VESM geographical coverage



Source: Vivid Economics

- **Whole Energy System Investment Model (WeSIM).** WeSIM model is an electricity system optimisation model that estimates the pattern of investment in and operation of electricity system resources which minimises the overall electricity system cost, given constraints to ensure reliability, meet system-level carbon emission targets and respect the characteristics of the electricity system. WeSIM has been widely used to investigate the future of the electricity system, with a focus on power sector decarbonisation. Key features of WeSIM include:
    - ◊ Detailed characterisation of all relevant electricity system resources. WeSIM models generation, network, storage, demand response and interconnection resources.
    - ◊ Detailed characterisation of electricity system reliability. WeSIM models reliability needs in detail, including adequacy, inertia, reserve and response.
    - ◊ Accurate modelling of important electricity system characteristics. WeSIM accurately represents power flow limits, dynamic characteristics of generation plants, and operational constraints of storage and demand response.
- WeSIM is used to adjust the power sector characterisation of VESM and improve the realism of the power sector results:
    - ◊ Improved representation of system reliability (both adequacy and security)
    - ◊ Improved representation of demand and generation profiles (hourly, weekly, monthly, seasonal), and associated balancing.
- WeSIM is a model developed by Imperial College, and fully peer reviewed. Vivid runs a version of WeSIM through a partnership with Imperial College.
    - ◊ Improved characterisation of technology mix, based on the system value of different generation technologies

1.2 Land Use - Model of Agricultural Production and its Impact on the Environment (MAgPIE)

- Model of Agricultural Production and its Impact on the Environment (MAgPIE) land-use model to be used as per 2019 – not owned by Vivid, but available open-source, and run by Vivid staff with input from PIK (which has developed the model).
- MAgPIE is a spatially explicit partial equilibrium model, in which food demand is estimated using population, GDP, dietary assumptions, and demand elasticities from the GTAP database. The model then determines the least cost way to meet that food demand, while accounting for biophysical constraints including those on land and water, as well as potential crop yields. Biophysical limits are estimated in LPJmL, a separate PIK model that translates climate projections from global climate models into physical constraints relevant for agriculture.
- These limits are an input to MAgPIE, which takes them as given. MAgPIE endogenously models investment in agricultural technological change and irrigation, and in so doing captures the effect of potential future increases in agricultural productivity.
- This framework therefore captures land use competition between varying uses, such as forestry, bioenergy, and agriculture and models how this competition evolves over time. Please see here for a more technical description of the model.

- MAgPIE was selected to support this project as the most fit-for-purpose tool given the project aims. Broadly, the objectives of the global modelling were to explore the impacts of climate change mitigation policies and transition risk on land use and food production systems.
- Table 2 lays out how MAgPIE capabilities supports delivery of these objectives.

Table 2 MAgPIE capabilities support project objectives

Modelling objectives	MAgPIE capabilities	MAgPIE limitations
Examine the implications of land-based carbon mitigation policies and other societal shifts on the AFOLU sector.	Mitigation policies can be implemented and tested straightforwardly in MAgPIE.	Threshold effects can cause abruptness in model outputs.
Assess price, production, and land use impacts on land assets	MAgPIE covers land assets, especially related to Forestry.	Has limited coverage of non-forestry land assets.
Disaggregate outputs spatially to obtain results at the regional or country level.	MAgPIE is connected to the dynamic vegetation model LPJmL, which uses a grid with a spatial resolution of 0.5°x0.5°. Outputs are aggregated at the regional and global levels.	Cells are assigned to one of 15 economic regions, and grid cells are clustered to make global computation tractable. This makes raw results unsuitable for localised estimation.
Provide estimates of the change in capex and opex of land related assets	MAgPIE produces estimates of the change in cost of water, fertiliser and energy to agricultural production.	Factor costs are based on area harvested, land use intensity, and a crop- and water-specific regional factor requirement meaning cellular factor costs are identical across cells within a region.

Source: Vivid Economics

Inputs and assumptions

The MAgPIE model is based on a set of inputs and assumptions which can be divided in four categories: land uses, biophysical constraints, socioeconomic assumptions and policies (Table 3 summarises these categories).

Table 3 Inputs and assumptions of the MAgPIE model

Categories	Description
1. Land uses	MAgPIE's initialisation is based on a land-use map which defines the different land uses with a spatial resolution of 0.5°x0.5° (55km x 55km at the equator). This layer determines how many hectares are attributed to each of the land uses, namely cropland, pastureland, other land, and primary, secondary and managed forest.
2. Biophysical constraints	Land-use changes and agricultural production are constrained by a set of biophysical assumptions, such as water availability or land suitability for crop production.
3. Socioeconomic assumptions	MAgPIE relies on a set of socioeconomic assumptions including trends in income, demographics as well as trade liberalisation and diet shifts.
4.Policies	Users can further define scenarios by selecting specific conservation, restoration and mitigation policies that are going to be applied to the land-use sector over the next decades.

Source: Vivid Economics

Demand

1.2.1 Agriculture:

Food and Feed. Food demand is calculated outside of MAgPIE in each modelling period (five-years interval). Historical demand is calibrated with FAOSTAT demand for different food products, while estimates of future demand are based on anthropometric food requirements, such as age, height and sex, as well as economic dynamics, such as GDP growth; and for selected behavioural shifts (e.g. in demand for beef). MAgPIE obtains food demand as an input at the beginning of each period, and it feeds back food prices (used to determine real income).

Materials. Material usage comes from FAO's "other utils" category and includes for example the use of agricultural products for cosmetics, chemical usage or textiles.

Bioenergy demand pathways are set by assumption. Bioenergy crops compete with food crops, and underlying growth in food demand causes shifts to second generation bioenergy crops, and drive limits to the global technical potential

1.2.2 Forestry:

Carbon sequestration. The introduction of a price for GHG emissions, creates demand for carbon sequestration (e.g. through afforestation) and turns negative carbon emissions into a commodity.

1.2.3 Supply:

Agriculture. Depending on how demand changes, agricultural production needs to change to match it in each region. There are three options to increase domestic agricultural supply: expanding agricultural land, intensifying production and increasing imports from other regions.

1.2.4 Forestry

Afforestation can be modelled exogenously and/or endogenously. For exogenous afforestation, the model takes into consideration either the national policies implemented (NPI) or the nationally determined contributions to the Paris agreement (NDC). Endogenous afforestation, on the other hand, is incentivized by the introduction a carbon price.

1.3 Macroeconomics - National Institute Global Econometric Model (NiGEM)

- NiGEM is an estimated macro-econometric set of country models. It has been estimated in a 'New-Keynesian' framework, which means that agents are assumed to be forward-looking, but nominal rigidities slow adjustment process to external events. Please see here for a more technical description of the model. It is a leading global macro-economic model used by financial regulators, and has been designed to provide macro-economic indicators of relevance to the financial sector. It has become the leading macro model used by regulators in looking at climate-related financial risk and has therefore been selected for use in IPR 2021 over G-CUBED.
    - ◊ The Bank of England PRA is currently using NiGEM for the BES Climate Stress Test
    - ◊ Over the last 18 months – and in partnership with Vivid – NIESR has been using NiGEM to assess the impacts of climate change risks on key macro-economic variables
    - ◊ Vivid Economics has used NiGEM on a number of recent projects, and have confidence that it can deliver the results required to achieve the IPR project goals in a manner that integrates successfully with our energy and land system models

1.3.1 Macroeconomic Model Development

- The macroeconomic modelling purely reflects the scenarios developed within the energy and land use modelling.
- Each of those are sub-systems of the macro-economy – representing partial equilibrium components of the macro-economy. The real economy systems from climate change to those systems are fed into the macro-economic model.
- The remainder of the macro-model calibration – particularly the monetary relationships associated with real economic activity – remain unaltered by the scenario.

2 2019 IPR Model Overview

2.1 Overview of the public modelling outputs produced in IPR 2019 work

IPR 2019 produced the Forecasted Policy Scenario (FPS), publishing a set of scenario outputs that are publicly available for others to use. This includes a set of scenario variables similar to what other public domain scenarios provide (e.g. the IEA). Since its release, a number of third parties have used the scenario outputs to run climate risk scenario analysis based on FPS. For example, The Carbon Tracker Initiative, 2dii, Blackrock and FitchRatings have all publicly stated that they used the scenario.

Alongside the FPS, IPR 2019 also produced investment impact analysis, publishing a set of sub-sector asset valuation impacts that are publicly available for others to use. This dataset was also built into a simple tool that allows investors to enter their portfolio holdings by asset class and get an impact estimate.

2.2 Overview of the public reports produced in IPR 2019 work

A significant proportion of the public outputs were in the form of detailed reports written to inform how investors look at this risk. Those are available in full on PRI's website, and received significant coverage in conferences, trade journals and mass media.

2.3 Description of the models used

IPR 2019 used a set of models with a proven history of use in policy and commercial settings. The core energy, land and macroeconomic system models were initially developed by academic institutes and are thoroughly peer reviewed. The models were run by a combination of Vivid modelling team members with input and guidance from academic modelling teams that developed the original versions of the models. The asset valuation model represents a proprietary Vivid model, developed since 2017. This model builds on a number of components, including a core 'cost and competition' model which Vivid has deployed in projects for the UK government, European Commission and private sector clients for roughly a decade.

These models used were:

- **TIAM energy system model** – not owned by Vivid, but available to Vivid through an Imperial College version which we ran jointly with Imperial staff. Please see here for a description of the model. Note TIAM is not publicly available, though it can be accessed on a commercial consulting basis.
- **MAgPIE land-use model** – not owned by Vivid, but available open-source, and run by Vivid staff with input from PIK (which has developed the model). Please see here for a description of the model.
- **Gcubed macro model** – not owned by Vivid, but licensed by Warwick McKibben to Vivid for this project, and run by Vivid in collaboration with Warwick and his team. Please see here for a description of the model.
- **The Vivid Net Zero Toolkit asset valuation model** – developed and owned by Vivid and run by Vivid for this project. Please see the appendix here of a report with a description of the model structure for the version of the model used for IPR.

- Miscellaneous spreadsheet models used to create various bespoke outputs requested by the consortium for specific reports.

More information on IPR is available here.