OFFICIAL MASTER IN ENERGY SECTOR

MASTER THESIS
IMPACT OF THE CARBON POLLUTION REDUCTION SCHEME ON THE AUSTRALIAN ELECTRICITY SECTOR.

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ABBREVIATIONS.

AAU – assigned amount unit
AEMO – Australian Energy Market Operator
Aud – Australian dollar
cAud – Aud cents
CDM – clean development mechanism
CER – carbon emission reduction
CPRS – Carbon Pollution Reduction Scheme
EA – emission allowances
ERU – emission reduction unit
ETS – emission trading scheme
GW – giga-watt
GWh – giga-watt hour
JI – joint implementation
kW – kilo-watt
kWh – kilo-watt hour
MRET – Mandatory RET
MW – mega-watt
MWh – mega-watt hour
NEM – national energy market
NEMMCO – national energy market management company limited
NRET – New South Wales RET
NSW – New South Wales (Australian state)
p.u. – per unit
REC – renewable electricity certificate
REM – renewable energy market
RET – renewable electricity target
RMU – removal unit
QLD – Queensland (Australian state)
SA – South Australia (Australian state)
TAS – Tasmania (Australian state)
VIC – Victoria (Australian state)
VRET – Victorian RET
Summary

This paper reflects the analysis of Australian electricity market in couple with environmental policies that have been applied by now and that are planning to be introduced in the near future.

The main concern of the research consists in determination of the influence of Carbon Pollution Reduction Scheme (CPRS) on the Australia economy. CPRS will be introduced in 2011. Because of high impact of electricity sector in total amount of greenhouse gas emissions (35%), it was considered important to focus more on the Australian electricity market simulation.

The impact analysis that new emission market provides is interesting both for participants and for institutions (regulator, market operator, government). From the participants’ point of view, cost internalization of emissions introduces high uncertainty in their management strategies: to generate electricity and buy permits, to change or improve the technology, to invest in carbon-free generation etc. From the institutional prospective, the best design of emission trading scheme (ETS) should be reached, taking into consideration other environmental policies that have been introduced in Australia by now. The design of the future ETS should lead to the most efficient resource allocation. Simulation and examination of the possible impacts will help to avoid the negative consequences and to determine the effectiveness of CPRS proposed.

There are no similar studies for Australia in open access. The only model that exists by now is the one developed by the Climate Change Department of Australia. But the results as well as the model itself are not available for the public use. But there are several models for European countries and for United States. The results of these experiences can be used as a departing point on the new Australian stage. A lot of useful lessons could be learned from that. At the same time this models cannot be applied directly to the Australian case because there is a number of initial differences. First of all, the framework of Australian CPRS differs from the existent ETSs introduced in other countries. Secondly, the electricity generation mix is completely different: cheap conventional coal is the major energy source for the Australian electricity sector while in Europe or USA the mix is more diversified. That is the reason why the separate model for Australian case was decided to develop.

This current research is beneficial from scientific and social point of view as well as from the company’s prospective. Social aspect is important because the main objective of the Government is not only carbon emissions reduction but also its implementation in the most cost-efficient way. The simulated model helps in evaluation of the proposed CPRS from the economical point of view and also will lead to the proposal of some changes in order to become more efficient. Taking into consideration that the investigation is performed for one of the Spanish main utilities Union Fenosa Group, can be underlined the practical value of obtained results that consists in their using in strategic decision making. Company uses the simulation model to decrease the risk associated with the entrance in the Australian Electricity Market.

The paper consists of seven chapters. The First Chapter reflects an overview of the Australian Energy Sector that includes an investigation of existent energy sources, electricity generation mix and the description of the National Energy Market (NEM). In Chapter 2 is explained in details CPRS, which influence is the main focus of the current research. In the Chapter 3 are represented other existent environmental policies that take place in Australia. These policies are reflected in the model as well. In the Chapter 4 starts the description of the simulation model developed in the frame of the current research. In order to provide an impact analysis of CPRS were developed a number of
scenarios that represent “possible futures” in Australia. These scenarios are described in the Chapter 5. In Chapter 6 the results of different scenarios are presented and analyzed. Last Chapter of the paper is devoted for final conclusions.
Chapter 1. Australian Energy Sector.

In the Chapter 1 the Australian Energy Sector is described. The description starts from the brief overview of the country. Aspects related to its existent energy sources, forecasts in consumption are explained in detail. Electricity sector is examined from the point of view of energy sources. The chapter provides explicit information about the current structure of Australian electricity market, its main actors and the rules they should follow as market participants.

1.1. Overview of Australia.

Australia is characterized by relatively low population (21 million people) and large territory (the 6th largest country in the world). The major part of the population is concentrated in the east coastal region.

One of Australia’s key strength is its abundance of energy resources: coal, natural gas, uranium, and petroleum. Its own energy consumption is dominated by domestic coal that is mainly used as a primary energy source for power generation. Petroleum makes up a large share of energy consumption. Due to its declining output, Australia is facing with the constantly growing dependence on petroleum imports. There are rich reserves of uranium in the country but by now Australia has been exporting all the uranium extracted and has not been using it for its own needs. On the contrary, in the case of natural gas, during the last two decades Australia has increased its consumption. It is expected that this tendency will be maintained over the medium term.

Australia is one of the countries that belong to the Organization for Economic Cooperation and Development (OECD) and is a large energy exporter. Australia is the largest coal exporter in the world and is the fifth largest exporter of liquefied natural gas (LNG). It is planned to expand energy export in the future as Asian demand for coal and LNG is on the rise.

1.2. National energy consumption forecasts.

Australian Bureau of Agriculture and Resource Economics (ABARE) have realized projection about the consumption of primary energy and electricity in the next twenty years.

Energy consumption projection:

- Natural gas is expected to have the fastest grow during the projection period.
- Primary gas consumption is projected to rise by 2.6% over the period.
- Electricity sector will increase by 37% its primary gas consumption.
Electricity consumption projection:
- Gross electricity generation in Australia is considered to grow by an average in 2% each year (from 257 TWh in 2005-2006 to 415 TWh in 2029-2030) and the peak growth will be 2.9%.
- Electricity demand growth differs from state to state. In Western Australia (WA) it is expected growth by 94% during the projection period.

In the Section 1.3 electricity generation side is examined. The current situation that takes place in the Australian electricity markets as well as the future trends are described below.
1.3.1. Coal.

Coal is currently the cheapest and most dominant fuel source for Australian generating assets. In National Electricity Market (NEM) 70% of installed capacity and 87% of generating capacity is coal based.

According to the information provided by the Australian system and market operator NEMMCO, the retirement of the certain units is planned in the next several years.

It is expected that with the changes in new environmental commitment on the country level, the share of coal in the generation mix will be significantly reduced.

1.3.2. Natural gas.

Natural gas is the second dominant resource in Australia and is considered to grow rapidly due to:

- Significant increase in demand, especially peaking demand;
- Limited growth in coal based generating assets, excluding the capacity expansion and technical improvement of existing ones;
- Complex of environmental policies (current and planned);
- Potential alternative to sell LNG to the offshore markets.

1.3.3. Hydro.

Main hydro potential in Australia is concentrated in Tasmania (TAS) and in the Snowy mountains territory that corresponds to New South Wales (NSW) and Victoria (VIC).

The hydro resource of Australia is limited and new hydro assets are unlikely to be constructed. However the upgrade of existing hydro units or small run-of-river developments may continue.

1.3.4. Renewable energy.

Currently 90% of electricity generation is based on fossil fuels. The rest 10% mainly consists of hydro generation. The low share in generation mix represents other renewable sources, although this generation is likely to grow due to the strong effort of renewable policies across the countries. Wind has very high potential and is considered as a main source of renewable energy for Australia in the future.

Next figures illustrate existent generation mix for installed and generated capacity.

*Figure 3. Generation Mix by Fuel. Installed capacity (MW).*

![Generation Mix by Fuel. Installed capacity (MW).](source: ABARE Australian Energy Projections to 2029-2030.)
1.4. **National Electricity Market.**

The major Australian wholesale electricity market ("energy only") is the National Electricity Market (NEM). It includes five states: Queensland (QLD), New South Wales (NSW), Victoria (VIS), Tasmania (TAS) and South Australia (SA). The Northern Territory and Western Australia are always excluded because of the lack of electrical interconnections.

The NEM started in December 1998 and currently comprises a physical spot market. Spot market is characterized by the energy traded through a commodities-type pool and a spot price every 5 minutes (averaged over half hour periods). The marginal generator selected to produce determines spot price. Due to interconnection constraints, marginal spot prices are different for NEM regions.

The National Electricity Market Management Company Limited (NEMMCO) fulfils role of market operator as well as system operator role for NEM. In other words, NEMMCO is responsible for managing the wholesale spot electricity market taking into account transmission elements of the physical power system. From the 1st of July 2009 AEMO (Australian Energy Market Operator) became market operator.

1.4.1. **Regional prices.**

The NEM is characterized by the regionally based pricing where the price for each point in the network is determined in relation to a common regional reference node price. When the network operates below its maximum technical transmission capacity, electricity prices in NEM regions have the small difference because of the transmission losses. However when interconnector operates on its maximum capacity, the prices differs significantly from one NEM region to another.

1.4.2. **Spot prices.**

Trading in NEM is performed on the half hour interval basis. The spot price corresponds to the clearing price to match demand and supply. It is taken as an average price of six 5-minutes interval prices.

For each NEM region the spot price is published at the end of each trading interval.

There was introduced the price cap and price floor in order to limit spot price. Currently in NEM price cap is equal to 10,000 Aud/MWh and the price floor value is minus 1,000 Aud/MWh.
1.5. Generation. Main players.

The generation side in Australia has specific structure. The previous structure before the mid-1990s was similar to vertically integrated monopoly. Following the restructuring in mid-1990s, the generation side became similar to fully competitive unbundled structure in some states and to the unbundled structure with the limited competition in others.

In New South Wales, Victoria and South Australia more than 15 producers represent the generation and the structure there can be considered a competitive one.

In the case of Tasmania and Queensland the main generation share is in the ownership of 3-6 companies, with the major part of public utilities. This introduces the market power on the state level and therefore limits competition.

The detailed description of the generation side in each state can be examined in Annex 1.
Chapter 2. Climate change policies in the Australian framework.

Climate change is an international problem and Australia is making an effort in order to decrease its negative impact. Chapter 2 provides the information about previous, current and future steps performed in the direction of climate change mitigation in Australia.

2.1. Garnaut Climate Change Review.

In September 2007 professor Ross Garnaut committed the report to the current prime minister of Australia (the Leader of the Opposition in the past) Kevin Rudd.

Garnaut Final Report made clear that the costs of inaction would be greater than the costs of responsible mitigation. In addition, the aggregate costs of action are modest, and the benefits of action (and the cost of inaction) increase over time, becoming more observable in the second half of this century and beyond. The Garnaut Final Report considers that “the overall cost to the Australia economy is manageable and in the order of one tenth of one per cent of annual economic growth”. It goes on to conclude that “the costs of well-designed mitigation, substantial as they are, would not end economic growth in Australia, its developing country neighbours or the global economy; unmitigated climate change probably would”.

It is often easier for governments to focus on immediate circumstances at the expense of long-term challenges, but ignoring these challenges only makes them worse. Analysis from the Australian Treasury and Professor Ross Garnaut demonstrates the longer the Australian Government will wait to take action on climate change, the more it will cost.

The Government accepted the key findings of the Garnaut Final Report and decided that the most prospective way to approach to the problem of climate change is to join the global action that reduces the risks of dangerous climate change and builds mechanism for deep cuts in emissions on the global level.

2.2. Kyoto protocol.

In December, 2007 Kevin Rudd, the prime minister of Australia, ratified Kyoto protocol indicating the Governments commitment to climate and environment.

According to the protocol, the target to reduce emissions by 60% on 2000 level by 2050 for Australia was set. During the first commitment period (2008-2012), the nation has to restrict emissions down to 108% of 1990 level. However, it is expected that this target will be overshoot at least by 1%.

2.3. Carbon Pollution Reduction Scheme.

The mechanism proposed in order to deal with the climate change problem and to reduce the carbon dioxide emissions is emission-trading scheme (ETS). ETS will establish a market for carbon emission permits, which supply will be restricted by the ETS cap. Australia’s Carbon Pollution Reduction Scheme (CPRS) will set an emissions cap, which will be gradually reduced over time.

This measure will ensure Australia’s low-emissions path with the low transition cost and incentives to develop and invest in low-emissions technologies. CPRS will be the key mechanism for achieving substantial emissions mitigation in a responsible manner and at the lowest possible cost.
2.3.1. National emission trajectory.

It was expected the Scheme to start in July with the target of 20% of 2000 level reduction by 2020, 2010 with the predefined target for the first compliance period. According to this, the first indicative national emissions trajectory would be defined as:

- In 2010–11, 109 per cent of 2000 levels;
- In 2011–12, 108 per cent of 2000 levels (corresponds to the Australian target under Kyoto treaty);
- In 2012–13, 107 per cent of 2000 levels.

In May 2009 was declared that CPRS will start one year later, in July 2011 while the emission reduction target will be increased up to 25%. After that announcement, the indicative national emission trajectory has not been redefined yet. It is expected that it will have the same tendency.

According to design of the CPRS, the trajectory for the next years should be announced 3-4 years in advance.

2.3.2. Mechanics of cap and trade scheme.

Emitters of greenhouse gases have to acquire a permit for every tonne of greenhouse gas that they emit. The quantity of emissions produced by firms will be monitored, reported and audited. At the end of each year, each liable entity will need to surrender a permit for every tonne of emissions that has produced in that year.

In a cap and trade scheme, aggregate emissions are capped at the level that is consistent with the environmental objective. The cap sets a limit on the aggregate annual emissions from all the covered types and sources of emissions.

The level of the CPRS cap determines its environmental contribution: the lower the cap, the more the abatement that must occur.

Carbon pollution permits could enter the market either by auction or by administrative allocation. As long as the cap remains unchangeable, the way permits enter the market does not significantly affect the abatement outcome. Whether a company receives carbon pollution permits for free or purchases them in the market, it will face the same incentives. Companies are likely to be willing to pay for permits if their internal costs of abatement are higher than the price of permits and to directly reduce their emissions if their internal costs of abatement are lower than the price of permits. Companies that own permit would be willing to sell them if the revenue received from selling permits exceeds the profits from using them.

The Government will auction the majority of the ETS carbon pollution permits. Auctioning is considered the most efficient way of distributing permits, since those who value them most highly will buy them. However, certain categories of companies will receive permits by administrative allocation. The possibility for those firms to sell permits got for free can be interpreted as a transitional assistance measure.

CPRS will include six greenhouse gases that are covered under the Kyoto Protocol. It will control around 75 per cent of Australia’s emissions and involve mandatory obligations for around 1000 entities. Initially, emissions from agriculture will not be covered.

As well as driving actual emissions reductions, the introduction of a carbon price provides a financial incentive for investment in low emissions technology research, development and commercialisation. A carbon cap should also lead to consumer behavioural changes that support a lower carbon economy. For example, higher
electricity prices will provide an incentive for consumers to conserve energy in their homes.

2.3.3. Carbon market.

There are several elements of ETS design that will contribute to an effective and efficient market:

- Carbon pollution permits will be created as personal property;
- Permits will be tradable;
- Permits will be able to be banked indefinitely;
- Will be allowed short-term borrowing restricted by 5%;
- Banking and borrowing will help promote a smoother carbon price path;
- There is a penalty of not complying with the target of 40 Aud/tonne of CO2. Paying this penalty does not save emitters from surrendering the necessary permits.

2.3.4. Carbon price.

As in European case, CPRS will create carbon pollution permits that are distinct to the Australia’s international (Kyoto protocol) units. It will provide Australian Government with the possibility to manage better its international obligations.

The balance of supply and demand for permits will determine carbon price. Pricing volatility, and upside price risk, will be reduced by:

- Coverage of the major sectors of economy;
- The ability to bank and borrow permits, which can help promote a smoother carbon price path;
- Unlimited access to international market of emission permits that will decrease the prices on the national market. If there are no restrictions on international emissions trade, Australia’s emission price will be determined by the global price that will provide an effective price cap on the domestic prices (In the scenarios the Treasury has modelled, Australia’s emission price is equal to the global price, with an allowance for changes in the exchange rate.)

2.3.5. International market.

CPRS has been designed to be able to link with international carbon markets. As demonstrated by the Final Garnaut Report and the Treasury modelling, access to an international carbon market can play an important role in reducing the overall costs of the global (and Australian) mitigation effort. An international carbon market already exists under the Kyoto Protocol. In Australia will be recognized the next Kyoto units:

- Certified Emission Reduction (CER) is generated under Clean Development Mechanism (CDM – for offset projects in developing countries). This mechanism does not lead to a net increase in global abatement because the use of CERs in Australia allows for an increase in domestic emissions. However, it lows the cost of introduction of the emission constrain.
- Emission Reduction Units (ERUs) created under Joint Implementation (JI) mechanism, for offset projects in developed countries. The Kyoto Protocol JI mechanism allows a country with a Kyoto Protocol target to implement emissions reduction projects, or projects that enhance
carbon sinks, in another country that also has a Kyoto Protocol target. The abatement created by such projects is recognized in the form of emission reduction units (ERUs), which can be counted in the Kyoto Protocol target of the country that instigated the project. ERUs created under the Kyoto Protocol’s joint implementation mechanism would be recognized for compliance purposes in CPRS.

- Removal units (RMUs) are units issued by a Kyoto Protocol country on the basis of land use, land-use change and forestry activities. Few countries are likely to be in a position to generate RMUs, so the potential for trade in RMUs is likely to be limited. Removal units would be recognized for compliance purposes in CPRS.

Assigned amount units (AAUs) as well as international non-Kyoto units will not be recognized under CPRS during the 2011-2013-commitment period.

The unlimited access to the international market has advantages and disadvantages. From one hand, it will decrease carbon prices on the national market and make them equal to international carbon prices. From another hand, it will introduce number of difficulties and administrative costs related to proof procedures of the fact that the emission reduction really took place.

European countries decided to introduce or not the quantitative restriction on the number of permits that could be bought on the international market. In Australia case this question became a debateable one. According to the first proposal of CPRS in Green Paper, it was planned to introduce the maximum percentage of international permits bought in the international market in order to comply with the target. This proposal was supported by the main Australian utilities. The reason is that the unlimited access provides the risk of not decreasing national emissions. By introducing the limit on the acceptance of international credits will enable to focus more on domestic abatement.

However, the Australian Government is confident that, even with unlimited access to international units, Australia’s use of the Kyoto Protocol flexibility mechanisms will be supplemental to domestic action. The advantage of not limiting the amount of international credits is that domestic compliance costs would be minimized in this case because liable entities would buy international units only if the units were less expensive than domestic options. Moreover, unlimited access to Kyoto units will provide more liquidity into the Australian market. By now it has been decided not to introduce any quantitative limitations in the use of eligible international units for compliance in CPRS.

Another important point is that on the first stage of CPRS introduction was decided not to allow sale and transfer of Australian domestic units to international markets. It was done in order to facilitate the smooth start and to minimize the implementation risk.

2.4. European Emission Trading Scheme. Lessons for Australia.

Australia is not the first country that is implementing cap-and-trade carbon scheme. In the frame of EU ETS had been finished the trial period (2005-2007) and in 2008 started the first commitment period that will last till 2012. Consequently, Australia can bring up some lessons from the European experience that will be useful.

The first important point is to determine correctly the emission cap. In the trial period in Europe the emission rights were assigned excessively. The target was reached
easily with no effort from the companies’ side. This became the main reason of carbon price equal to zero. It is suggested to keep up relative scarcity in emission permits.

The second important point is to provide stable regulatory framework for market participants. In the European case there was high level of uncertainty and actors did not know if after the trial period emission trading would take place or not. It leaded to scarce investments in low-emission technologies. In Australia it is expected to know the national emission trajectory in advance, as it will give more confidence to the market participants.

2.5. Update of the CPRS.

Australian Government has a substantial commitment to reduce their carbon pollution by 60 per cent of 2000 levels by 2050.

In order to follow this target the intermediate steps in carbon reduction were determined. It was decided that by 2020 Australia has to reduce carbon emissions by 15% below 2000 levels. Also there is an unconditional 5 per cent reduction in carbon pollution below 2000 levels by 2020.

However in December 2008 Prime Minister Kevin Rudd said that the emissions would be cut only by 5% of 2000 level by 2050. But if other countries go for stronger reductions, Australia will cut of the emissions up to 15%.

This declaration was not the last one because in several months the emission reduction objective was significantly increased up to 25%. This last announcement happened in May 2009 in Copenhagen. Moreover, in May 2009, some other changes were introduced in CPRS. According to them:

- CPRS starts in July 2011;
- Carbon reduction target changes up to 25% of 2000 level up to 2020 year;
- During the first compliance year international market will be closed;
- During the first compliance year carbon price will be fixed and equal to 10 Aud/tonne of CO2.

In the previous chapter was discussed the new ETS named CPRS that from 2011 will introduce the restriction for all power generators in Australia on the total amount of carbon dioxide emissions per year. This scheme is aimed to the emission reduction at the least-cost basis. In the present chapter environmental policies that currently exist in Australia will be discussed. These policies encourage additional renewable generation by setting up an obligation on electricity retailers and large consumers to purchase a portion of their power from renewable sources. To facilitate this aim, tradable Renewable Energy Certificates (RECs) are being allocated to generators for every MWh of electricity generation qualifying as renewable under the Renewable Energy Scheme (RES). The tradable RECs are instruments that allow the Renewable Energy Targets (RET) to be met at least cost.

For the first time it was done in Australia on the national level in 2001. Currently there are several RESs in Australia introduced on the state or national level.

3.1. State level

There are two schemes on the state level that are currently in use. They are Victorian Renewable Energy Target (VRET) and New-South Wales Renewable Energy Target (NRET).

3.1.1. Victorian Renewable Energy Target

The Victorian Renewable Energy Target (VRET) requires electricity retailers in the state of Victoria to purchase 10% of their electricity consumption from renewable energy sources by 2016. Eligible renewable energy sources include hydro, wind, biomass, geothermal and solar, and must be located in Victoria. The target for Victorian Government is to have 3,274 GWh of additional renewable energy. It means that 374MW of renewable generation should be additionally installed in the state.

There was introduced the penalty $43/MWh (in 2007 dollars) for non-complying with the target, which corresponds to $61.40/MWh after taxes. The penalty acts as a price cap on the Victorian market for RECs.

VRET started in 2007 and will go on until 2030. In the Table 1 the target schedule for the next twenty years is represented. Banking of certificates is allowed. However, generators are only eligible to create Victorian renewable certificates for 15 years, so incentives to enter the market early will be diminished.

Table 1. Required amount of electricity from renewable energy sources by VRET.

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Target (GWh)</th>
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<tbody>
<tr>
<td>2007</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>193</td>
</tr>
<tr>
<td>2009</td>
<td>578</td>
</tr>
<tr>
<td>2010</td>
<td>963</td>
</tr>
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</tr>
<tr>
<td>2015</td>
<td>2,889</td>
</tr>
<tr>
<td>2016</td>
<td>3,274</td>
</tr>
</tbody>
</table>
Below there is a graphical representation of the Table 1.

The target ramps down after 2022 to reflect the fact that renewable energy projects developed to meet the initial target will no longer be eligible to create certificates after that period.

**Figure 5. VRET target.**

3.1.2. **New-South Wales Renewable Energy Target**

The New South Wales (NSW) Renewable Energy Target (NRET) requires retailers to source 10% of their energy consumption from renewable energy sources by 2010 and 15% by 2020. Eligible renewable energy sources include hydro, wind, biomass, geothermal and solar, and can be located in any of the states connected to the NSW by transmission lines.

The NSW Government has explicitly stated that it is seeking to align NRET with VRET. That is the reason why the penalty price for non-compliance of the scheme is corresponds to the Victorian penalty and is equal to $43/MWh (in 2007 dollars), which means $61.40/MWh after taxes. The penalty acts as a price cap on the NSW market for Renewable Energy Certificates (RECs).

The target for NSW Government is to have 1,317 GWh of additional renewable energy by 2010 and 7,250 GWh by 2020. The 7,250 GWh target will be held constant from 2020 until 2030, when the scheme ends. It means that 150 MW of renewable

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<thead>
<tr>
<th>Year</th>
<th>Generation (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>3,274</td>
</tr>
<tr>
<td>2018</td>
<td>3,274</td>
</tr>
<tr>
<td>2019</td>
<td>3,274</td>
</tr>
<tr>
<td>2020</td>
<td>3,274</td>
</tr>
<tr>
<td>2021</td>
<td>3,274</td>
</tr>
<tr>
<td>2022</td>
<td>3,274</td>
</tr>
<tr>
<td>2023</td>
<td>3,081</td>
</tr>
<tr>
<td>2024</td>
<td>2,696</td>
</tr>
<tr>
<td>2025</td>
<td>2,311</td>
</tr>
<tr>
<td>2026</td>
<td>1,926</td>
</tr>
<tr>
<td>2027</td>
<td>1,541</td>
</tr>
<tr>
<td>2028</td>
<td>1,156</td>
</tr>
<tr>
<td>2029</td>
<td>770</td>
</tr>
<tr>
<td>2030</td>
<td>385</td>
</tr>
</tbody>
</table>
generation should be additionally installed in the states by 2010 and 828 MW should be installed by 2020.

The target schedule is shown in Table 2 below.

Table 2. Required amount of electricity from renewable energy sources by NRET.

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Target (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>439</td>
</tr>
<tr>
<td>2009</td>
<td>878</td>
</tr>
<tr>
<td>2010</td>
<td>1,317</td>
</tr>
<tr>
<td>2011</td>
<td>1,910</td>
</tr>
<tr>
<td>2012</td>
<td>2,504</td>
</tr>
<tr>
<td>2013</td>
<td>3,097</td>
</tr>
<tr>
<td>2014</td>
<td>3,690</td>
</tr>
<tr>
<td>2015</td>
<td>4,284</td>
</tr>
<tr>
<td>2016</td>
<td>4,877</td>
</tr>
<tr>
<td>2017</td>
<td>5,470</td>
</tr>
<tr>
<td>2018</td>
<td>6,063</td>
</tr>
<tr>
<td>2019</td>
<td>6,657</td>
</tr>
<tr>
<td>2020</td>
<td>7,250</td>
</tr>
<tr>
<td>2021</td>
<td>7,250</td>
</tr>
<tr>
<td>2022</td>
<td>7,250</td>
</tr>
<tr>
<td>2023</td>
<td>7,250</td>
</tr>
<tr>
<td>2024</td>
<td>7,250</td>
</tr>
<tr>
<td>2025</td>
<td>7,250</td>
</tr>
<tr>
<td>2026</td>
<td>7,250</td>
</tr>
<tr>
<td>2027</td>
<td>7,250</td>
</tr>
<tr>
<td>2028</td>
<td>7,250</td>
</tr>
<tr>
<td>2029</td>
<td>7,250</td>
</tr>
<tr>
<td>2030</td>
<td>7,250</td>
</tr>
</tbody>
</table>

Below there is a graphical representation of the Table 2.

Figure 6. NRET target.


3.2. National level

In year 2001 was introduced Mandatory Renewable Energy Target (MRET) that was expanded in 2009. New MRET is called “expanded MRET” and will come into force in 2010.

3.2.1. Mandatory Renewable Energy Target

In 2001 the Commonwealth Government has introduced legislation to mandate the supply of an additional 2% of their electricity from renewable sources that corresponds to 9,500 GWh of renewable energy by 2010. The scheme remains at 2% target from 2010 till 2020. Eligible renewable energy sources include hydro, wind, biomass, geothermal and solar, and can be located in any of the states-members of NEM.

The MRET scheme has been implemented with a high penalty for non-performance of $40/MWh that is equal to $57/MWh after taxes. This penalty would effectively provide a price-cap on RECs for renewable energy.

The target for the Commonwealth Government was to have 3,615 MW of additional renewable generating capacity installed by 2010.

The target schedule is shown in Table 3 below.

Table 3. Required amount of electricity from renewable energy sources by MRET.

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Target (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>1,100</td>
</tr>
<tr>
<td>2003</td>
<td>1,800</td>
</tr>
<tr>
<td>2004</td>
<td>2,600</td>
</tr>
<tr>
<td>2005</td>
<td>3,400</td>
</tr>
<tr>
<td>2006</td>
<td>4,500</td>
</tr>
<tr>
<td>2007</td>
<td>5,600</td>
</tr>
<tr>
<td>2008</td>
<td>6,800</td>
</tr>
<tr>
<td>2009</td>
<td>8,100</td>
</tr>
<tr>
<td>2010</td>
<td>9,500</td>
</tr>
<tr>
<td>2011</td>
<td>9,500</td>
</tr>
<tr>
<td>2012</td>
<td>9,500</td>
</tr>
<tr>
<td>2013</td>
<td>9,500</td>
</tr>
<tr>
<td>2014</td>
<td>9,500</td>
</tr>
<tr>
<td>2015</td>
<td>9,500</td>
</tr>
<tr>
<td>2016</td>
<td>9,500</td>
</tr>
<tr>
<td>2017</td>
<td>9,500</td>
</tr>
<tr>
<td>2018</td>
<td>9,500</td>
</tr>
<tr>
<td>2019</td>
<td>9,500</td>
</tr>
<tr>
<td>2020</td>
<td>9,500</td>
</tr>
</tbody>
</table>

Below there is a graphical representation of the Table 3.
After the year 2005, generation companies stopped to invest in renewable generation because of restriction in the certificates’ eligibility period of 15 years. This became the major motivation for some of the states to bring an initiative of introducing new state RET schemes. Also the Commonwealth Government decided not to stop with this environmental policy but to expand it for ten years more. The national scheme that appeared after is described in the next Section.

### 3.2.2. Expanded Mandatory Renewable Energy Target

In 2009 the Commonwealth Government has decided to expand MRET for ten years more asking for additional 20% of their electricity from renewable sources to supply by 2020. The scheme remains at 20% target from 2010 till 2020. In other words, additional 45,000 GWh of renewable power is needed by 2020. Eligible renewable energy sources include hydro, wind, biomass, geothermal and solar, and can be located in any of the states-members of NEM.

It is expected that because of the high target, expanded MRET will be finally combined with existing MRET, VRET and NRET.

Still there is no defined level of penalty for retailers not complied with the target. The forecasts include very high level for penalty such as 300 Aud/MWh. This penalty should be sufficiently high for providing effective price-cap on RECs for the scheme with very high target.

The target for the Commonwealth Government is to have 16,800 MW of additional renewable generating capacity installed by 2020.

The target schedule is shown in Table 4 below.

<table>
<thead>
<tr>
<th>Calendar year</th>
<th>Target (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>8,100</td>
</tr>
<tr>
<td>2010</td>
<td>12,500</td>
</tr>
<tr>
<td>2011</td>
<td>14,400</td>
</tr>
<tr>
<td>2012</td>
<td>16,300</td>
</tr>
<tr>
<td>2013</td>
<td>18,200</td>
</tr>
<tr>
<td>2014</td>
<td>20,100</td>
</tr>
</tbody>
</table>
3.3. Interaction between different RET schemes.

Concluding from the description of all RET schemes applied in the Commonwealth, can be expected existence of three markets for renewable energy:

- The MRET and expanded MRET applied for all the Australian states.
- VRET scheme introduced in Victoria and eligible only for VRET certificates.
- NRET scheme introduced in NSW and eligible only for renewable generators physically connected to the NSW power system.

The eligibility criteria to create RECs for different schemes means that the prices under expanded MRET scheme will be affected by VRET and NRET schemes. It happens because the renewable producer in Victoria, for instance, has the possibility to choose between these three markets. From another hand, renewable generator cannot surrender the same REC on two markets out of three discussed above. This implies an additive character of MRET, VRET and NRET schemes.
Chapter 4. Modeling the Australian market.

4.1. Methodology.

In the framework of the current investigation it was decided to use simulation. The model aims to evaluate the impact of the introduction of new Carbon Pollution Reduction Scheme (CPRS) in Australia. Simulation was considered as the most appropriate tool for impact analysis mainly because of the constant changes in CPRS characteristics, such as emission reduction targets for 2020, national emission trajectory, degree of the international market openness, etc. Flexible model will help to determine the effect of CPRS with different input data in the changing environment.

Simulated model includes all the environmental policies developed by now in the country at the national as well as at the state level. By modeling the real size Australian electricity market it becomes possible to recognize the effects of combination of different emission reduction instruments, such as RECs’ market and international market developed under emission trading scheme (ETS). In analysis will be found out the influence of this combination on the amount of new investments in electricity sector, on the generation mix and on the electricity and REC prices.

For evaluation of the model’s sensitivity, scenario analysis is applied. In the research are determined the most probable “futures” as well as the extreme ones. Each scenario under consideration is characterized by its own list of factors. Scenario analysis allows detecting the influence of each parameter on the system and also the influence of their combinations.

The simulation period starts in 2010 and lasts till 2030.

The criteria chosen for analysis of the whole system is the least cost approach. It is assumed that all the decisions in the system are made from the single regulator’s prospective.

4.2. Problem identification.

The problem statement for regulator consists in costs’ optimization, taking into account technical restrictions and environmental commitments. System costs include the cost of electricity production, emission certificates cost, investment costs and also the inflow obtained from selling of RECs under one of the RET schemes in the country.

In other words, the problem for the regulator can be formulated in the next way:

How to minimize the cost of electricity production that corresponds to the constantly growing demand, with the amount of carbon dioxide emissions per year that do not run-over the determined in CPRS emission cap and having in generation portfolio the certain percentage of the renewable energy (that corresponds to the RETs in the country).

4.3. Assumptions

4.3.1. General.

1) All the costs and prices are expressed in Australian Dollars 2009/2010 (1 Aud = 0.75 $ USA).

2) No inflation is assumed during the period of modelling.

3) Discount rate for new entrants is assumed to be equal to 7% (post-tax real WACC).
4.3.2. Electricity market.
1) The market operates to maximise efficiency and is made up of well-informed and rational participants.
2) There is no limitation in the model on the amount of possible investments each year.
3) The price for the energy non-served is not included in the objective function because the investments are considered to be unlimited and the model is deterministic.
4) No ramp rates and unit commitments are included in the model in order to avoid high computational effort.
5) Energy demand growth will be included in the model as an input data. Peak demand growth is not included separately in the model because of assumption that existing reserve margin is enough to cover the peak loads.
6) The load is divided in 5 levels: 3 for working and 2 for non-working days.
7) Dispatching of new power plant starts at the investment decision point.
8) The production of power unit is assumed to be a continuous variable (no discrete values).
9) No energy transportation losses are assumed for the modelling.
10) In order to decrease the quantity of variables in the model and to make it easier to understand it, all generating units have been grouped into equivalent virtual power plant according to the technology for each state. The complete list of the technologies is represented in the Appendix 2.

4.3.3. Generations units’ characteristics.
1) Availability, heat rates and capacity factors of all power plants in the NEM (renewable and non-renewable ones) are based on historical data and other open sources. (See Appendix 3).
2) Costs for renewable generation project are derived from the open information sources. (See Appendix 5).
3) Capacity factors for wind generation vary from 0.30 to 0.38 that depends on the state and on location. (See Appendix 5).
4) The capacity factor for existing regulated hydro power plants are based on the normal inflow conditions. (See Appendix 4).
5) In the model is assumed that hydro profile during all the period from 2010-2030 repeats the situation that took place in 2006. That year in Australia was neither dry nor wet – was the normal one. This assumption appears because during the long term modelling dry and wet periods will compensate each other. That is the point also the point why the stochastic modelling of the water level in reservoir is not included in the analysis.

4.3.4. Fuel costs.
1) Gas prices are considered to move in line with Treasury’s assumptions.
2) New entrant’s gas prices are based on the NEMMCO Report 2007.
3) There are different fuel (gas, coal) prices for different states. (See Appendix 3).
4) In the model the unique fuel price is considered for each state. No fuel transportation cost is assumed for the model.

4.3.5. Emission Trading.
1) International market is considered to be completely open for the Australian generators.
2) Prices for emission permits are externally imposed and are modelled by the means of scenarios.
3) According to the values sourced from Treasury’s modelling of CPRS Scheme under 5% abatement scenario, the assumed emission permit prices will increase approximately from 30Aud/tonne of CO2 to 55Aud/tonne of CO2 in 25 years (from 2011 to 2030).
4) According to the values sourced from Treasury’s modelling of CPRS Scheme under 25% abatement scenario, the assumed emission permit prices will increase approximately from 30Aud/tonne of CO2 to 75Aud/tonne of CO2 in 25 years (from 2011 to 2030).
5) In the case that CPRS is introduced with carbon prices fixed during the first year, it is assumed that banking of carbon credits will be unavailable during this year.

1) It is assumed the availability of the perfect information for all the REM participants. That is the reason why long term bilateral contracts that are common on REM become equal to the competitive market price. Consequently, RECs market is assumed to be a perfectly competitive one.
2) REM is introduced in the model, as a restriction on the minimum amount of renewable energy should be generated each year: the sum of produced renewable electricity has to be larger than the target set on the national and on the state level.

4.4. Structure of the model.
The entire model is divided into three sub-models that correspond to the Electricity Market, Emission Market and Renewable Energy Market. The objective function under minimization integrates these parts in a single model by including sub-models’ outputs in its structure. In the next Sections can be found overviews of each component and the corresponding modeling assumptions.

4.4.1. Electricity market.
For the modeling was decided to limit the Australian Electricity market by NEM. NEM is a competitive wholesale power market that covers the dense populated part of the country interconnected by high voltage transmission lines. In other words, under consideration are five states out of seven. More information about NEM can be found in the Section 1.4.
Each state is considered a single market node that is characterized by specific supply and demand. The dispatched regions are interconnected by the transmission links that restrict the interchange between them. Consequently there are different levels of electricity prices in each of the dispatch regions.

In the next sections will be characterized the Australian electricity market. Will be given the approach to model its supply, demand and transmission links.

4.4.1.1. Supply.
Total installed capacity in NEM is about 43 462 MW (“NEMMCO statement of opportunities” published on 31.12.2007). In the modeling frame all the capacity is divided in the next categories:

1) **Existent and New.**

*Existent* includes those power stations that have been built before the modeling period started. Among the existent capacity was decided to mark out power plants that are in construction nowadays. In the model those plants will enter in use in a certain year (this information is public). They are not included into *New* generation because the investment decision was made in advance, so there is no any influence of renewable policy measure which the effect is analyzed in this paper. There are also some plants that from the predefined year will be retired, for instance plants that use old technologies etc. In the determined year they will disappear from the list of *Existent* generation.

Where the state’s capacity is insufficient to meet the demand, the model is allowed to build *New* capacity that is assumed to install immediately when the investment decision is made.

As it was mentioned in the list of assumptions, the technological development is not included as an uncertain variable in the design of our future because the study period is limited by 20 years and we assume that during that period nothing significant in the evolution of technology can happen. However, *New* technology is introduced in the model with the improved characteristics comparing to the *Existent* ones. For instance, the efficiency of Combined Cycle Gas Turbine is considered to improve from 47% to 60%. This kind of assumption implies technological development but in indirect way.

2) **With/Without REC**s (renewable or non-renewable capacity).

Capacity that is considered to be renewable under one of RET Schemes according to the model gets an amount of REC that correspond to its production level. This generation is included in the category named *With REC*. As far as the model implies the co-existence of three RET schemes: expanded MRET, VRET and NRET, the generator that produces 1 MWh of green energy will receive one REC which can be submitted to one of these three schemes because they have additive character.

Other capacity that does not generate renewable energy is attributed to the capacity *Without REC*.

4.4.1.2. Technologies.
There are technologies that represent the generation side of the states. In the model, in order to decrease the quantity of variables and to simplify the analysis of the output was decided to group all the power plants into the equivalent plant per technology of electricity production. Existent and new technologies taken under consideration are listed in *Appendix 2*. 
According to the information provided by NEMMCO, the generation mix is different for each state and corresponds to the Figure 9 below.

**Figure 9. Generation mix by state.**

It is assumed the existence of the total competition between different technologies on the state level.

The number of the next operational parameters characterizes each technology:
- Technology type;
- Variable cost (cAud/MWh);
- Installed power (MW);
- Emission rate (t/MWh): CO2, SO2, NOx;
- Particles’ emissions (g/kWh);
- Use ratio.

Besides the parameters mentioned above, New technologies are characterized by:
- Investment cost (cAud/kW);
- Potential of the resource for the country/state (in the case of renewables technologies).

Characteristics of hydro technologies include the information about:
- Maximum power generated for regulated hydro (GWh);
- Annual inflows for regulated hydro (GWh);
- Values for pumping yield for pumping stations (MW);
- Maximum capacity for pumping stations (GWh).
4.4.1.3. **Demand.**

In the modeling the demand is allocated between five load levels. It is assumed that three of them represent peak, valley and base load for working days and other two levels – valley and base for weekends and holidays.

Each year is divided into 12 periods where each period corresponds to one month.

The hourly demand profile used in the model is based on the statistics reported by NEMMCO (Jan-Dec 2007).

The forecasts about growth of energy consumption in the country is based on the NEM statement of opportunities 2008 Energy and Maximum Demand Projection Report and is considered to be equal to 2% per year.

4.4.1.4. **Transmission links.**

The model’s design includes five dispatch regions that correspond to five NEM states. Transmission lines with the restricted capacity interconnect the states. The way of interconnection is represented on the Figure 10 where all capacity values are in MW and the transfer capability is indicative.

*Figure 10. Scheme of high voltage interconnections between NEM states.*

The reflection of the transmission lines’ introduction in the model leads to the possibility to satisfy the demand in the region not only by its own generation but also by the import from the neighbor regions.

4.4.2. **Emission market.**

Emission market is considered to become internationally open from the second year of CPRS introduction. All the agents are obliged to obtain certain number of emission allowances that corresponds to their emission level by the end of the year. Accessibility of the international market increases the supply of carbon credits for Australian generators.
As it was mentioned in the Section 2.4, Australia plans to commit the higher emission reduction target of 25% of 2000 level by 2020. Because of the high carbon dependency of the Australian national economy, rising up the target will lead to the increasing of the carbon prices and the electricity price as well. Opening the market on the international level will make a significant influence on the Australian allowances’ prices by decreasing them and making them equal to the international prices. This will give a chance for mid-level emitters to remain competitive.

In the model emission market is modeled by setting the fixed international price. Different prices on carbon emissions are simulated using a number of scenarios.

It was shown, that international carbon prices would influence on the national carbon prices in Australia. From another hand, Australia is expected to become a large buyer of carbon credits on the international level; consequently its own emission targets will affect the price level on the international market. That is the reason why the national regulation and emission target establishment will play a great role in determination of the carbon prices.

In the model the price is assumed to grow during the modeling period. The starting point is considered be equal to 30 Aud/tonne of CO2 and the velocity of growth changes depending on the national emission target.

Depending on the target (for year 2020), Australian government will commit, the 5%-25% of reduction comparing to the 2000 emission level. In the case of 5% reduction, the growth rate is assumed to be equal to 1.7% and in the case of 25% - to 4.5%. These data is from the report that describes the Treasury’s modelling of CPRS.

The possibility of banking and borrowing the carbon credits was introduced in the model. Banking is unlimited and is allowed between periods and super-periods. Borrowing, on the contrary, is limited. The maximum amount of carbon credits the generator can borrow in a short-term is equal to 5%.


As far as the renewable energy competes on the electricity market in terms of production, Renewable Energy Market represents only the stage for selling the renewable energy certificates (RECs).

RECs can be generated under one of the next Renewable Energy Schemes: VRET, NRET or expanded MRET (that from the starting of study period will be put into practice).

Each of the RETs has its own trajectory of targets to comply with, its own areal space and time length. The detailed explanation of these 3 schemes can be found in the Chapter 3.

One of the most important features that is reflected in the model, is the fact that RECs got in one scheme cannot be surrendered in the frame of another RET scheme. It means that the schemes have additive character.

The design of REC market is performed in the next way. In the case of not complying with the target determined the RETs, the retailer must pay a penalty. The size of penalty after taxes is the same for NRET and VRET scheme is about 65Aud/MWh (in Aud 2009 year). The penalty for the expanded MRET scheme is not defined yet. There are only some projections about the possible penalty value of 300Aud/MWh. The penalty for expanded MRET scheme is considered to be significantly higher comparing to the state level schemes mainly because of the very high target has to be reached. Penalty works in the model as a price cap for RECs.

Possibility of unlimited banking is an important characteristic taken into consideration. It leads to the smoother changes in REC prices in Australia.
Long-term bilateral contracts are widely used in REM in order to hedge the risks. However, as it was stated in the Section 4.3, under the assumption of the availability of the perfect information for all the market participants, bilateral contracts become equal to the spot-market.

In the model REM is represented by the flat demand predetermined by RET and by the certain supply of RECs each year that corresponds to the generation level in the state.

4.5. Mathematical structure.

The problem is stated in terms of Linear Programming by means of setting the objective function that tends to be minimized and by introducing linear constraints that describe technical, economical and environmental aspects of the model. Solutions are represented by Decision Variables (see Chapter 4.5.1.3) that satisfies all constraints (optimality conditions in couple with market equations) and minimize the objective cost function.

The complete mathematical formulation of the problem is represented below.

4.5.1. Model statement.

In this Section will be defined all the symbols that were used in the model for different purposes. They are parameters, variables, dual variables, etc.

4.5.1.1. Indices.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$</td>
<td>Pumped-storage technologies</td>
</tr>
<tr>
<td>$ce$</td>
<td>Existing technologies</td>
</tr>
<tr>
<td>$cn$</td>
<td>New technologies</td>
</tr>
<tr>
<td>$cr$</td>
<td>Renewable technologies</td>
</tr>
<tr>
<td>$e$</td>
<td>States</td>
</tr>
<tr>
<td>$f$</td>
<td>Run-of-the-river technologies</td>
</tr>
<tr>
<td>$h$</td>
<td>Hydro technologies</td>
</tr>
<tr>
<td>$n$</td>
<td>Load levels</td>
</tr>
<tr>
<td>$p$</td>
<td>Periods</td>
</tr>
<tr>
<td>$RET$</td>
<td>Renewable Energy Target (VRET, VRET + NRET, VRET + NRET + expanded MRET)</td>
</tr>
<tr>
<td>$s$</td>
<td>Sub-periods</td>
</tr>
</tbody>
</table>

In order to simplify the presentation was assumed that $ce$ and $cn$ are subsets of $e$. Talking differently, $ce$ and $cn$ are the technologies that correspond to the state $e$. Although it is technically incorrect, is will shorten the explanation.

$RET$ was determined in this way in order to simplify its mathematical representation. The RET schemes have an additive character. There is no possibility to surrender the same REC for several schemes.

4.5.1.2. Parameters.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{h,p,s}$</td>
<td>Hydro inflows for hydro technology $h$ in sub-period $s$ of the period $p$ [TWh]</td>
</tr>
<tr>
<td>$\bar{b}_b, \underline{b}_b$</td>
<td>Maximum and minimum capacity of pumped-storage technology $b$ when pumping [GW]</td>
</tr>
<tr>
<td>$ci_{cn}$</td>
<td>Capacity investment cost [M€/GW]</td>
</tr>
</tbody>
</table>
Duration of load level $n$ in sub-period $s$ in the state $e$ [kh]

States that participate under RET scheme.

Minimum renewable energy supplied with renewable energy certificates under the Renewable energy target scheme RET in period $p$ [GWh]

Maximum power flow from the state $e$ to the state $e_1$ in period $p$ [MW]

Power generation by run-of-the-river technology $f$ in load level $n$ in sub-period $s$ of the period $p$ [GW]

Maximum and minimum capacity of pumped-hydro generators $h$ [GW]

Maximum and minimum capacity of pumped-storage technology $b$ [GW]

Maximum installed capacity for technology $cn$ at period $p$ in the state $e$ [TW]

Linear heat rate of existing thermal technology $ce$ in the state $e$ [Mcal/kWh]

Linear heat rate of new thermal technology $cn$ in the state $e$ [Mcal/kWh]

Initial allowance price on the international market in period $p$ [Aud/tonne of CO2]

Emission price in period $p$ [Aud/tonne of CO2]

Gas price in the state $e$ [Aud/Mcal]

Year of starting of the study period (equal to 2010)

Initial electricity demand in load level $n$ in sub-period $s$ in the state $e$ [GWh]

Electricity demand function in load level $n$ in sub-period $s$ of period $p$ [GWh]

Electricity demand growth [%]

Amount of allowances could be borrowed from the next period [%]

Maximum and minimum hydro reserve of hydro technology $h$ [TWh]

Penalty under the scheme RET [Aud/MWh]

Maximum and minimum rated capacity of existing thermal technology $ce$ [GW]

Minimum rated capacity of new thermal technology $cn$ [GW]

Maximum possible share of wind technology in the generation mix in load level $n$ in sub-period $s$ of period $p$ in the state $e$ [%]

Fuel cost of existent and new thermal technology $ce, cn$ in the state $e$ [GW]

Utilization factor of existent and new thermal technology $ce, cn$ [p.u.]
4.5.1.3. Decision variables.

- $b_{b,p,s,n}$: Power consumption by pumped-storage technology $b$ in load level $n$ in sub-period $s$ of period $p$ [GW]
- $E_{e_{i}p,s,n}^e$: Power flow from the state $e_i$ to the state $e_i$ in load level $n$ in sub-period $s$ of the period $p$ [MW]
- $h_{b,p,s,n}$: Power generation by pumped-storage technology $b$ in load level $n$ in sub-period $s$ of period $p$ [GW]
- $h_{h,p,s,n}$: Power generation by pumped-hydro technology $h$ in load level $n$ in sub-period $s$ of period $p$ [GW]
- $l_{e,cn,p}$: New installed capacity in technology $cn$ in period $p$ in the state $e$ [GW]
- $q_{e,ce}^{emis}$: Amount of allowances for existent generation $ce$ in period $p$ in the state $e$ [Mt CO2]
- $q_{e,cn,p}^{emis}$: Amount of allowances for new generation $cn$ in period $p$ in the state $e$ [Mt CO2]
- $R_{p,s,n}$: Hydro energy reserve of hydro technology $h$ in load level $n$ in sub-period $s$ of period $p$ [GWh]
- $re_{e,RET,p}^{fail}$: Amount of renewable energy certificates not surrounded under the scheme $RET$ in period $p$ [MWh]
- $re_{e,RET,p}^{bank}$: Amount of renewable energy certificates banked under the scheme $RET$ in period $p$ [MWh]
- $t_{e,c}^{p,s,n}$: Power generation by existent thermal technology $ce$ in load level $n$ in sub-period $s$ of period $p$ in the state $e$ [GW]
- $t_{cn,p,s,n}$: Power generation by new thermal technology $cn$ in load level $n$ in sub-period $s$ of period $p$ in the state $e$ [GW]

4.5.1.4. Dual variables.

- $\mu_{e,ce,p,s,n}^{elec}$: Electricity price in load level $n$ in sub-period $s$ of period $p$ in the state $e$ [Aud/kWh]. In the model description for simplification purposes is called $p_{e,ce,p,s,n}^{elec}$ (see Section 4.5.1.4)
- $\mu_{p}^{RET}$: REC’s price under $RET$ scheme in period $p$ [Aud/MWh]. In the model description for simplification purposes is called $p_{p}^{RET}$ (see Section 4.5.1.4)

4.5.1.5. Objective function.

Below is determined the objective function for linear programming problem. The objective for the system regulator is to minimize all the costs: electricity production costs, costs of carbon credits purchasing, investment costs and also costs of renewable energy certificate surrounding – for all the decision study period.

Mathematically, the next function should be Minimized:
\[
\sum_{e} \sum_{p} \sum_{i} \sum_{n} D_{e,p,s,n} \cdot i_p \cdot (V_{e,ce} \cdot \alpha_{e,ce} \cdot t_{ce,p,s,n} + V_{e,cn} \cdot \alpha_{e,cn} \cdot t_{cn,p,s,n}) + \\
+ \sum_{e} \sum_{p} i_p \cdot p_{p}^{\text{emis}} \cdot (q_{e,ce,p}^{\text{emis}} + q_{e,cn,p}^{\text{emis}}) + \sum_{p} \sum_{\text{RET}} i_p \cdot r_{\text{penalty}}^{\text{RET}} \cdot r_{\text{fail}}^{\text{RET},p} \quad \forall e,p,s,n
\]

4.5.1.6. **Auxiliary equations.**

The following equation describes the total power generation in each state which is represented by the sum of thermal, hydro, pump-storage and run-of-river electricity production that is dispatched from the least-cost prospective. This generation should be equal to the total consumption on the state level, more export from the current state to all its neighbors, excluding import in the state under examination.

\[
q_{e,p,s,n}^{\text{elec}} = \sum_{\text{ce}} t_{ce,p,s,n} + \sum_{\text{cn}} t_{cn,p,s,n} + \sum_{\text{he}} h_{h,p,s,n} + \\
+ \sum_{\text{ce}} (h_{b,p,s,n} - b_{b,p,s,n}) + \sum_{\text{fe}} f_{f,p,s,n} + \\
- \sum_{e_1,s_1} \text{Exp}_{e_1,s_1}^{e} + \sum_{e_1,s_1} \text{Exp}_{e_1,s_1}^{e} \quad \perp \mu_{e,p,s,n}^{\text{elec}} \quad \forall e,e_1,p,s,n
\]

Where \(\mu_{e,p,s,n}^{\text{elec}}\) is a dual variable to the demand equation that corresponds to electricity price \(p_{e,p,s,n}^{\text{elec}}\).

Demand is assumed to grow with the constant speed equal to \(q_{e,p,s,n}^{\text{elec}}\) within each period. According to this, demand in a period \(\bar{p}\) can be determined in the next way:

\[
q_{e,p,s,n}^{\text{elec}} = q_{e,s,n}^{\text{elec},0} \cdot (q_{e,p,s,n}^{\text{elec}})^{p-p_0} \quad \forall e,p,s,n,p_0 = 2010
\]

4.5.1.7. **Constraints.**

The model developed in the frame of the present research is long-term one. According to this, constraints mainly consist of hydro management constraints, emissions and production constraints and constraints on investment decisions.

*Production constraint.*

Power generated from existent or new energy source in each load level is restricted by the use coefficient of that technology multiplied on its total installed capacity.

\[
t_{ce,p,s,n} \leq q_{ce} \cdot I_{ce,p} \\
t_{cn,p,s,n} \leq q_{cn} \cdot I_{cn,p} \quad \forall p,s,n,ce
\]

*Hydro scheduling*

Energy generated during the period by hydro or pumped-hydro technology is limited by:

- Initial reservoir level;
- Final reservoir level;
- Hydro inflows during that period.
It is known the initial level of reservoir in the first period and its level on the end of the last period.

\[ \sum_{n} D_{e, t, n} \cdot h_{h, p, s, n} - R_{h, p, s} + R_{h, p, s, n+1} - A_{h, p, s} \leq 0 \quad \forall p, s, n \]

**Pumped storage scheduling.**

The system regulator uses pumped-storage facilities in order to decrease price peaks: when the electricity prices are low, electricity is bought (water is pumped) and when the prices are high, electricity is sold. In order to take into account pumping stations, in the model are predetermined two constraints.

First constraint can be explained as an introduction of the limit for pumped-storage unit generation that should be less than the energy pumped during the period.

\[ \sum_{n} D_{e, t, n} \cdot (h_{b, p, s, n} - \rho_{b} b_{b, p, s, n}) \leq 0 \quad \forall e, p, s, n, b \]

The second one constrains the total production during the period.

\[ \sum_{n} D_{e, t, n} \cdot h_{b, p, s, n} \leq R_{h} \quad \forall e, p, s, n, b \]

**Investment constraints.**

The first investment constraint appears from the hypothesis that the installed capacity in the current period in the same state should be more or equal comparing to the capacity in the previous period.

\[ I_{e, cn, p-1} - I_{e, cn, p} \leq 0 \quad \forall e, cn, p > p_{0} \]

The second investment constraint refers to the *Production Constraints* shown before. It reflects that while making the investment decision, the technology’s utilization factor (that corresponds to the maximum generation output) should be taken into account.

The amount of investments in each state is considered to be unlimited.

**Emission Allowances.**

The permitted amount of carbon emissions in the state is restricted by the total amount of carbon credits bought beforehand (in one of the previous years because of the possibility of banking).

\[ \sum_{e} \left( \sum_{e_{ce}, s} D_{e, t, n} \cdot (\tau_{e, p, s, n} \cdot t_{e, p, s, n}) + \sum_{c_{ce}, s} D_{e, t, n} \cdot (\tau_{c, p, s, n} \cdot t_{c, p, s, n}) \right) \leq q_{e}^{\text{emis}} \quad \forall e, p, s, n \]
Renewable Energy Certificates.

Renewable technologies are participating on the same market as the thermal ones. So for them are applied the same power constraints as those described above. However, there are some additional constraints for renewable energy that were taken into account. One of them represents the restriction for the energy potential of the source: for instance, wind or solar potential for each state. Time horizon corresponds to the study period for the whole model equal to 2030.

\[ I_{e, cn, p = 2030} \leq I_{e, cn, p = 2030} \quad \forall e, cn \in cr \]

In the model was introduced an additional restriction. It limits the wind share in the generation mix. The main reason of this limitation is the following. Wind technology by now is mostly developed and the most economically efficient one. By this reason, in the case of strong environmental enforcement from the side of Australian Government, wind technology will be widely spread in Australia. But this can lead to the imbalance in the generation mix because there will be high share of intermittent energy source and scarcity of the base-load renewable energy. According to this consideration, was decided to limit the wind share by:

- 30% in the states with scarce hydro resources;
- 50% in other states.

\[ t_{c=e^{\text{wind}}, p, s, n}^e \leq w_{e, p, s, n} \cdot \sum_{e} q_{e, p, s, n}^{\text{elec}} \quad \forall e, p, s, n, cn and ce \in e \]

Total renewable energy generated by existent or new installations receives RECs that are sold on the REC market. The amount of the certificates that participate at the market should be higher than the minimum quota set up by government. The next constraints reflect this statement for three RET schemes included in the model. Moreover, the possibility of banking and additive relation between RET schemes are reflected.

\[ \sum_{s, n, e} D_{e, s, n} \cdot t_{e, cn, p, s, n} + \sum_{s, n, e} D_{e, s, n} \cdot t_{e, ce, p, s, n} + \sum_{p_1 \leq p} rec_{\text{bank}}^{\text{RET}, p_1} - rec_{\text{bank}}^{\text{RET}, p_1} + rec_{\text{fail}}^{\text{RET}, p_1} \geq E_{p, \text{RET}} \quad \perp \mu_p^{\text{RET}} \quad \forall p, \text{RET}, cn and ce \in cr, e \in e_s \]

The price for REC under each scheme is obtained as a dual variable of the quota constraint \( \mu_p^{\text{RET}} \).

4.5.1.8. Boundaries.

The next bounds were introduced in the model.

\[ q \leq q_{e, p}^{\text{omin}} \quad \forall e, p \]

\[ b_\overline{b} \leq b_{b, p, s, n} \leq b_\underline{b} \quad \forall b, p, s, n \]

\[ h_\overline{h} \leq h_{h, p, s, n} \leq h_\underline{h} \quad \forall b, p, s, n \]

\[ h_\overline{h} \leq h_{h, p, s, n} \leq h_\underline{h} \quad \forall h, p, s, n \]
\[
\begin{align*}
I_{e,cn,p} & \leq I_{e,cn,p} & \forall e,cn,p \\
I_{ce} & \leq I_{ce,p,s,n} & \forall ce,p,s,n \\
I_{cn} & \leq I_{cn,p,s,n} & \forall cn,p,s,n \\
R_h & \leq R_{h,p,s} & \forall h,p,s
\end{align*}
\]

4.6. Computing the model.

It is difficult to solve the real size problem, as the one described above, using the commercial solvers such as CPLEX. This kind of solvers they have size limitations.

In order to have the possibility to run the model on the normal computer, it was decided to reduce the size of the model by aggregating all power plants in the system into one representative plant per technology type and state. However, among the input data for the model was introduced also the information about the portfolio of each generating company. This gives the possibility to get the particular information about each firm’s position in the market (if the market is still assumed to be absolutely competitive).

Finally, the real size model was run with approximately 500,000 variables and equations (the GAMS code is presented in Appendix 6). One single run takes 5-7 minutes depending on the complexity of scenario that is modeling. Each model run gives the optimal solution was found. This procedure was repeated for all scenarios that were decided to include in research. For facilitation of these operations was developed complex of subprograms in MatLab 7.1. Moreover, all results became easy to see and to analyze after creation of the excel report that uses the model output.
Chapter 5. Scenario analysis.

In this Chapter will be described the approach how to determine possible “futures”. The methodology consists in the identification of all the factors that affect the system. Then the classification of the chosen factors between important and unimportant, certain and uncertain should be performed. The combination of factors that are at the same time important and uncertain will create scenarios. Each scenario will be explained in detail.

5.1. Factors.

In this Section will be marked out those factors that can radically or not affect the results.

1) Technological development.
   This factor means that electricity-producing technologies can become cheaper or can emit less.
   This factor I would consider as an important one because the initial investments that introduce a significant barrier entry for new players will be reduced. Consequently, because of the investment flow, will appear more generation and the market prices will change.
   Taking into consideration that technological improvement could also tackle the emission rate of the particular technologies, it will mainly affect the amount of emission permits that should be bought by the generator in order to comply with the rules that CPRS imposes. So, the less certificates will be bought and the emission market price will change. Also the investment in the improved technology will become more attractive.
   In other words, technological development should be considered as an important factor for the model but at the same time it is certain. At least till the end of the study period (till 2030) nothing crucial is expected to happen. That’s the reason why I consider this factor important but certain one.

2) Hydrology.
   The inflows that happen each year are important for the electricity system balance but during the significantly long period can be considered certain: dry and wet years will compensate each other.

3) Demand growth.
   Demand growth is a clear incentive for the generators to invest more. That is the reason why it is a very important factor. At the same time it cannot be considered as the certain one mainly because the great number of other factors that affects it. For instance, according to the NEMMCO forecast in 2008 the energy demand during the next several years should growth in 2% per year and the peak demand should growth in 2.9%. In reality, because of the crisis, during the first half of the year 2009 has been observed a small slump in demand in some states of the Commonwealth. This factor in the current study will be considered as an important and uncertain one.
4) **Fuel prices.**
Gas market is very volatile nowadays. This makes gas prices uncertain. In Australian Electricity Market where the marginal pricing is applied, gas is the main fuel for peaking technologies (CCGT). In other words, gas prices directly determine the electricity market prices. It is the reason why gas prices become very important in the whole system.

5) **Environmental regulation.**
National trajectories, targets and the way of CPRS introduction characterize the environmental regulation. It can be represented by:

a) Time frame:

- Start in 2010 like it was decided on the moment of the submission of White Paper (December 2008).
- Start in 2011 like it was announced on May 5 2009 in Copenhagen.

b) Target:

- 5% by 2020 year comparing to the 2000 emission level as it was decided in December 2008;
- 15% by 2020 year comparing to the 2000 emission level as it was decided in Green Paper in 2008;
- 25% by 2020 year comparing to the 2000 emission level as it was proposed in Copenhagen on May 5 2009.

The way the regulation will come into force strongly affects the whole system in terms of electricity prices, new investments, prices on emission permits and also the whole amount of carbon dioxide emissions per year. This factor is important and uncertain (taking into account all the changes made in the governmental decision during the last several years) but it will influence finally on carbon prices that are described below. That is the reason why in the scenario development we will take into account the combined effect of international carbon prices and of national environmental regulation.

6) **International carbon prices.**
This factor is important and uncertain. In the simulation study carbon prices can vary between the values 10-40 EUR that approximately corresponds to the 15-70 AUD according to the current exchange course. In reality experts forecast that prices on international carbon market will rise even more in a long term prospective. Because Australia is one of the largest emitters in the world, the national emission targets will influence on the amount of permits has to be bought on the international market and thereby affect on the international carbon prices.

7) **Nuclear investments.**
From one hand, investments in nuclear generation are risky. Without the governmental assistance is seems quite uncertain the possibility of introduction of nuclear generation in the current mix. From another hand, this factor is an important one. Australia has one of the largest uranium resources in the world (2nd place after Canada) and some political parties consider
switching to nuclear for base load generation as the least cost option in decreasing the amount of carbon emissions. Also the majority of the citizen supports it. At the same time, there is a protest from NGOs because of the unsolved topic of nuclear wastes. How the situation can change during 20 years (our study period), nobody knows. That is the reason why it was proposed to introduce the possibility of new nuclear electrical power in the model as additional scenario.

5.2. Identification of scenarios.

The figure below represents the distribution of the factors described above:

**Figure 11. Factors classification.**

<table>
<thead>
<tr>
<th>Important and certain</th>
<th>Unimportant and certain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrology</td>
<td></td>
</tr>
<tr>
<td>Technology development</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Important and uncertain</th>
<th>Unimportant and uncertain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon prices on the international market + Environmental regulation</td>
<td></td>
</tr>
<tr>
<td>Demand growth</td>
<td></td>
</tr>
<tr>
<td>Fuel prices</td>
<td></td>
</tr>
<tr>
<td>Nuclear support</td>
<td></td>
</tr>
</tbody>
</table>

The factors in the red quadrant will be the basic ones for developing scenarios for our model. Their combinations determine 16 “possible futures”. Below there are 2 tables: one – scenarios without nuclear support and another one – with nuclear introduction.

**Table 5. Possible scenarios without support of nuclear investments.**

<table>
<thead>
<tr>
<th>NO Nuclear support</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
<th>Scenario 6</th>
<th>Scenario 7</th>
<th>Scenario 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intern. carbon prices + Envir. Reg.</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>High</td>
<td>High</td>
<td>Expected</td>
</tr>
<tr>
<td>Demand growth</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Gas price</td>
<td>Expected</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Expected</td>
<td>Expected</td>
<td>Expected</td>
<td>High</td>
</tr>
</tbody>
</table>

**Table 6. Possible scenarios with support of nuclear investments.**

<table>
<thead>
<tr>
<th>Nuclear support</th>
<th>Scenario 9</th>
<th>Scenario 10</th>
<th>Scenario 11</th>
<th>Scenario 12</th>
<th>Scenario 13</th>
<th>Scenario 14</th>
<th>Scenario 15</th>
<th>Scenario 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intern. carbon prices + Envir. Reg.</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>High</td>
<td>High</td>
<td>Expected</td>
</tr>
<tr>
<td>Demand growth</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>Expected</td>
<td>High</td>
<td>Expected</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Gas price</td>
<td>Expected</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Expected</td>
<td>Expected</td>
<td>Expected</td>
<td>High</td>
</tr>
</tbody>
</table>
Six highlighted scenarios I consider the most interesting ones:

- First two are extreme cases.
- Next two correspond to the high level of gas prices (that are very volatile in realty) and different level of carbon prices (that because of unstable environment regulation in Australia becomes difficult to forecast).
- The 5th scenario seems curious from the point of defining the clear input of the demand growth in the future.
- The last 12th scenario includes the possibility of introduction nuclear electricity power in the environment of high gas prices and high carbon prices. It is expected the galloping growth of nuclear energy share in total energy mix.
- On the last stage of research, according to the declaration of the prime minister that happened during the conference in Copenhagen in May 2009, I considered important to add one scenario more to the analysis. This scenario will totally correspond to the public statement of Kevin Rudd.

5.3. Scenarios’ description.

In this Section will be described the Base Case and all the Scenarios chosen beforehand.

**Base case**

Energy demand is increasing by 2% each year.
Capacity that was planned to install (that has all the permits, etc) will be installed.
There is no Scheme introduced till the end of the modelling period.
The inflows are as in average: the period is neither wet nor dry (it is forecasted the improvement of the hydrology profile by 2010).
Gas prices are about (1.18cAud/kWh; 1.44cAud/kWh) depending on a state.
Coal prices are about (0.21cAud/kWh; 0.54cAud/kWh) depending on a state.
All Renewable Energy Targets: VRET, NRET and expanded MRET – are in use.

**Scenario 1. Green Future.**
The Scheme will start in July 2011 with the target of 5%
International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 1.7% each year.
No investments in nuclear.
All the rest remains the same.

**Scenario 2. Green Present.**
Demand is increasing by 4% per year.
The Scheme starts in July 2011 with the higher target of 25%.
Gas prices increase in 5% starting from the first year of modelling
International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 4.5% each year.
No investments in nuclear.
All the rest remains the same.

**Scenario 3. Fuel matters.**
Demand is increasing by 2% per year.
The Scheme starts in July 2011 with the target of 5%.
Gas prices increase in 5% starting from the first year of modelling.
International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 1.7% each year.
No investments in nuclear.
All the rest remains the same.

Scenario 4.
Demand is increasing by 2% per year.
The Scheme starts in July 2011 with the target of 25%.
Gas prices increase in 5% starting from the first year of modelling.
International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 4.5% each year.
No investments in nuclear.
All the rest remains the same.

Scenario 5. High demand.
Demand is increasing by 4% per year.
The Scheme starts in July 2011 with the target of 5%.
International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 1.7% each year.
No investments in nuclear.
All the rest remains the same.

Demand is increasing by 2% per year.
The Scheme starts in July 2011 with the higher target of 25%.
International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 4.5% each year.
Support for investments in nuclear generation.
All the rest remains the same.

Scenario 13. PM (Prime Minister’s) expectations.
Demand is increasing by 2% per year.
The Scheme starts in July 2011 with the higher target of 25%.
First year of the Scheme (July, 2011 – June, 2012) the carbon prices are fixed and equal to 10 Aud/tonne of CO2.
From July 2012, international market will become open. International carbon prices are considered to be equal to 30 Aud/tonne of CO2 and increase by 4.5% each year.
No investments in nuclear.

All the scenarios explained above are presented in the next Table 7.
Table 7. Scenarios.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand growth</td>
<td>2% Expected 30+1.7%</td>
<td>4% Expected 30+4.5%</td>
<td>2% Expected 30+1.7%</td>
<td>2% Expected 30+4.5%</td>
<td>2% Expected 30+1.7%</td>
<td>2% Expected 30+4.5%</td>
<td>2% Expected In 2011: 10 From 2012: 30+4.5%</td>
</tr>
<tr>
<td>Fuel prices</td>
<td>Expected 5% growth 30+1.7%</td>
<td>5% growth 30+4.5%</td>
<td>5% growth 30+1.7%</td>
<td>5% growth 30+4.5%</td>
<td>5% growth 30+1.7%</td>
<td>5% growth 30+4.5%</td>
<td>5% growth 30+4.5%</td>
</tr>
<tr>
<td>Carbon prices on international market (Aud/tonne CO2)</td>
<td>30+1.7%</td>
<td>30+4.5%</td>
<td>30+1.7%</td>
<td>30+4.5%</td>
<td>30+1.7%</td>
<td>30+4.5%</td>
<td>30+4.5%</td>
</tr>
<tr>
<td>Emission reduction target by 2020</td>
<td>5%</td>
<td>25%</td>
<td>5%</td>
<td>25%</td>
<td>5%</td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td>Investments in nuclear</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

In the current Chapter were described all the factors that affect the model and all the possible scenarios that were considered interesting. In the next Chapter the results of each scenario will be shown and analyzed.
Chapter 6. Results.

In the current Chapter will be presented the results of the model. Below are listed the output parameters that were considered important for the current analysis:

- Generation mix;
- Electricity price;
- REC price;
- Emissions;
- Investments.

These parameters will be shown for the total NEM and in some cases for each state separately.


The overview of the future generation mix in relation with investments will be shown for all the NEM regions together.

6.1.1. Base Case.

In the case that nothing changes in terms of environmental concern, coal power plants remain in the mix as main producers: to use coal is still cheap because nobody should pay for emissions. Queensland with its cheapest coal becomes the main NEM power generator.

*Figure 12. Generation in NEM. Base Case.*

The share of renewable energy is growing accurately in the frame of RET schemes. It can be observed that renewable development is related to the state where it takes place. For instance, in Victoria there is a peak of investments in 2016. It is caused by the trajectory of VRET. According to it, starting from 2017 year there is no need for additional renewable generation in the state. For Victorian investors it seems wiser to go to other NEM states, with higher renewable energy potential (to South Australia, Tasmania or New South Wales), in order to comply with expanded MRET.
In the beginning of the study period, energy reserve margin is very high. And even existent gas power plants are not dispatched. CCGTs for satisfying the constantly growing demand start to generate at the end of study period.


First scenario mainly repeats the picture that takes place in the base case. However, the situation the electricity producers are fronted is different from the Base Case: now producers should pay for what they emit. But still the picture does not change. The reason is that carbon price on the international market is not high enough to force the change in generation mix.

Figure 13. Generation in NEM. Scenario 1.


In the second scenario situation strongly differs from the previous two cases (see Figure 14).

Figure 14. Generation in NEM. Scenario 2.
The situation is different because now all the producers should pay for what they emit and coal producer suffer mostly because of the high greenhouse emission rate from the coal generation. Because of the expensive emission allowances, generation mix becomes “greener” in a short-term prospective.

From the very beginning coal stops growing and in the final five years several coal producers even stop its generation. It is caused by high carbon prices in the international carbon market: from the economical prospective, it becomes more efficient to stop producing than to continue generating from coal energy source.

Share of CCGT and renewable generation starts to grow. However high gas prices prevents the extensive CCGT development in the country, allowing renewables to produce more than they have to by RET schemes.

It is interesting to see how high electricity prices on the national market (caused by high carbon prices) make investments in wind power generation economically viable. Even after the pressure of RET schemes becomes less, after 2020, when there is no increasing in the target, in the investment profile appears a new peak (see Figure 15).

Figure 15. Investments in NEM. Scenario 2.

From the Figure above it can be seen the flow of investments in three main technologies: wind, CCGT and electricity production from landfill gas. But the development of fuel-based and renewable technologies does not have the same tendency in all the states: for instance, the comparison is made for two NEM regions, New South Wales and Victoria (see Figure 16).

Figure 16. Generation in New South Wales. Scenario 2.
In NSW, major development gets renewable generation and mainly wind generation because of high wind potential in the state. It can be seen from the next Figure.

Figure 17. Investments in New South Wales. Scenario 2.

In Victoria CCGT is increasing its share. It can be seen from the Figure 18. Before the system has entered in use, in Victoria was a lot of installed CCGT capacity, however it was not dispatched. The reason is the least cost approach of the market operator. After the introduction of CPRS, CCGT production becomes cheaper because of low carbon emissions. And the installed CCGT capacity starts to be dispatched. Moreover because of high demand level, in 2026 appears the flow of investments in CCGT generation. It can be seen from the Figure 19.

Renewables start to develop more actively in last two years of the study period. From the Figure 19 can be concluded that the main renewable technology for investments is landfill gas electricity generation. Because of high electricity prices it becomes profitable investment in bio-fuel even with no RECs provided for that. It can be mentioned, that there is no additional wind development in Victoria because of low wind potential in the state.

Figure 18. Generation in Victoria. Scenario 2.
It should be observed that the main renewable development occurs in NSW and VIC states. It happens because of initial proactive environmental policies of these two states.

It can be concluded that Scenario 2 represents the extreme picture in the future with high gas prices, high demand growth and the emission reduction target of 25% of 2000 level by 2020. The generation profile is completely changed as well as the electricity prices. The last point will be shown in details in Section 6.2.

6.1.4. Scenario 3.

In the case third case, characterized by high gas prices the figure for generation mix repeats the results of Green Future scenario. There is almost no gas because of high fuel prices. At the same time, the national emission reduction target is not so high to make renewables grow faster than RET obliges. The scenario’s results demonstrate that change of gas prices in 5% in the case of low emission reduction target does not affect the vector of capacity extension in cleaner manner.

6.1.5. Scenario 4.

From the current scenario can be observed that from the year 2025, gas power plants become the second important producers (after coal). High carbon prices combined with the high emission reduction lead to the deep introduction with the
further usage of less emitting technologies, such as CCGT. Even high gas prices cannot stop the extensive development of CCGT generation in the country. The generation mix that corresponds to the Scenario 4 can be seen below on the Figure 21.

**Figure 21. Generation in NEM. Scenario 4.**

![Generation in NEM. Scenario 4.](image)

6.1.6. **Scenario 5. High demand.**

It can be seen from the figure below that the intensive growth in electricity demand (which is the main factor in Scenario 5) is covered by new CCGT installations in NEM regions. At the end of the study period the share of CCGT in electricity generation becomes almost equal to the share of coal production.

**Figure 22. Generation in NEM. Scenario 5.**

![Generation in NEM. Scenario 5.](image)

Investors prefer CCGT to coal because CCGT production is cleaner in terms of carbon emissions. Another important point is comparably low gas prices. Even in Queensland where coal is the cheapest possible energy source, during the last eight years of the study period, investments in CCGT become the main one.

Scenario without restriction on installing the nuclear power is absolutely different from all the other cases. Low variable cost of nuclear unit is the main advantage of nuclear technology. It does not allow to the other technologies to start its development: neither gas (with high fuel prices on the market) nor renewables (in the volume that exceeds RET) have the comparable scale.

In the case of secure investments in nuclear, generation mix will change in the way presented on the Figure 24.


The last scenario nowadays is considered as the most probable one. Renewable generation increases its share. However, it is expected to see gas generation as the most widespread one. Figure 25 reflects the picture of the future generation portfolio in NEM.
6.2. Electricity price.

The evolution of electricity price in different futures is shown on the example of one of the NEM states, New South Wales. On the Figure 26 are shown prices in relation to the Base Case electricity prices that correspond to 1.

Figure 26. Relative electricity price in New South Wales. Scenarios comparison.

The highest level of prices comparing to the Base Case is reached in the Scenario 2 if the CPRS target is equal to 25%, gas prices are higher and electricity demand grows faster than it is expected. In this case, electricity prices in NSW will be three times higher than in the case with no CPRS introduced. This price growth is not so high. If we take a closer look at another state Queensland (see Figure 27) where electricity generation is coal intensive and renewable potential is low, the increase in almost 3.5 times will be observed.
Figure 27. Relative electricity price in Queensland. Scenarios comparison.

From the both graphs can be seen that investments in nuclear generation allow introduction of CPRS (with strong commitment to reduce emissions of 25%) on a least cost basis.

Scenario 13. PM case, the most probable one even without high gas prices and high demand growth almost reaches the electricity price level of Scenario 2. Green present. This means that significant increase in prices is expected in the near future.

Table below represents the average growth of electricity price per year comparing to the Base Case results of 2010. In other words, Table 8 shows how the electricity consumers will be affected in each “possible future”.

Table 8. Average growth of electricity price per year comparing to the Base Case (results of 2010) in $AUD/MW.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>QLD</th>
<th>VIC</th>
<th>NSW</th>
<th>TAS</th>
<th>SA</th>
<th>NEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Future</td>
<td>1.00</td>
<td>1.063</td>
<td>1.06</td>
<td>0.95</td>
<td>0.89</td>
<td>1.03</td>
</tr>
<tr>
<td>Green Present</td>
<td>2.24</td>
<td>2.24</td>
<td>2.22</td>
<td>2.02</td>
<td>2.03</td>
<td>2.22</td>
</tr>
<tr>
<td>Fuel matters</td>
<td>1.03</td>
<td>1.11</td>
<td>1.10</td>
<td>1.00</td>
<td>0.94</td>
<td>1.07</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>2.00</td>
<td>1.96</td>
<td>1.97</td>
<td>1.88</td>
<td>1.75</td>
<td>1.97</td>
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<tr>
<td>High demand</td>
<td>1.57</td>
<td>1.62</td>
<td>1.64</td>
<td>1.52</td>
<td>1.46</td>
<td>1.60</td>
</tr>
<tr>
<td>Nuclear case</td>
<td>1.55</td>
<td>1.48</td>
<td>1.48</td>
<td>1.40</td>
<td>1.37</td>
<td>1.49</td>
</tr>
<tr>
<td>PM expectations</td>
<td>1.92</td>
<td>1.92</td>
<td>1.93</td>
<td>1.84</td>
<td>1.67</td>
<td>1.91</td>
</tr>
<tr>
<td>Base case</td>
<td>0.43</td>
<td>0.54</td>
<td>0.54</td>
<td>0.43</td>
<td>0.43</td>
<td>0.50</td>
</tr>
</tbody>
</table>

It can be seen that the electricity price is expected to increase by 1-2 $AUD/MW each year, depending on scenario and state.

6.3. REC price.

From the Figure 28 REC prices for different scenarios can be obtained. These prices are not absolute values that will take place in the future but they provide with the possibility to compare different scenarios with the Base Case.
In the majority of scenarios is observable the tendency of price reduction after the peak. It is caused by the fact that all RETs stop growing: there is no additional renewable energy required.

In some scenarios, REC price even becomes equal to zero. This result shows the interconnection with the price on electricity market that becomes high enough to cover all the expenses of renewable generators: they do not need anymore REC “assistance”.

The lowest level of REC prices is reached in the Scenario 2. Green Present with the highest electricity prices (see Section 6.3.). The highest peak in REC prices corresponds to the Base Case where prices on electricity market are provided by cheap energy from coal.

6.4. Emissions.

On the emission graph all scenarios are compared. It can be seen that in the case of secure nuclear investments, emissions could be reduced rapidly in 20 years.
Another important point is the great importance of demand. Even if the national emission reduction target is high, emissions’ level is higher than even in the Base Case, without environmental policy in force. Comparing two cases with high demand and high gas prices, the Green Future and the High Demand cases, can be marked out the influence of emission reduction target. If the target is low, emissions will go on growing to correspond to the fast demand. By making the target higher, emissions stop growing in 2025.

Emission trajectory in Fuel matters repeats the results from Base Case. It means that for Australia the CPRS introduction with 5% of emission reduction is not sufficient to decrease the emissions.

PM expectations developed under the assumption of higher target of 25% leads to considerable decrease in emissions.

6.5. Results. Summary.

Previously obtained results show the differences raised by the variations in factors’ values. The brief overview of the performed analysis is presented in a Table 9.

Table 9. Scenarios’ comparison. Main indicators.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Indicator</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
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<tbody>
<tr>
<td><strong>Base case</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>17.85</td>
<td>17.91</td>
<td>19.96</td>
<td>30.36</td>
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<td>Emissions</td>
<td>167.01</td>
<td>173.24</td>
<td>175.07</td>
<td>198.77</td>
<td>223.60</td>
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<td><strong>Green future</strong></td>
<td>Electricity price</td>
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<td>22.74</td>
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<td>Emissions</td>
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<td>173.24</td>
<td>174.67</td>
<td>198.47</td>
<td>220.88</td>
</tr>
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<td></td>
<td>Allowance price</td>
<td>n/a</td>
<td>32.09</td>
<td>34.91</td>
<td>37.98</td>
<td>41.33</td>
</tr>
<tr>
<td><strong>Green present</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>38.74</td>
<td>44.48</td>
<td>57.11</td>
<td>65.67</td>
</tr>
<tr>
<td></td>
<td>Emissions</td>
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<td>207.50</td>
<td>229.34</td>
<td>246.45</td>
<td>234.52</td>
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<td></td>
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<td>44.58</td>
<td>55.56</td>
<td>69.24</td>
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<td><strong>Fuel matters</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>22.74</td>
<td>24.76</td>
<td>28.90</td>
<td>39.31</td>
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<td></td>
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<td>173.26</td>
<td>174.67</td>
<td>198.68</td>
<td>220.99</td>
</tr>
<tr>
<td></td>
<td>Allowance price</td>
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<td>32.09</td>
<td>34.91</td>
<td>37.98</td>
<td>41.33</td>
</tr>
<tr>
<td><strong>Scenario 4</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>31.94</td>
<td>37.62</td>
<td>45.77</td>
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<tr>
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<td>Emissions</td>
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<td></td>
<td>Allowance price</td>
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<td>35.78</td>
<td>44.58</td>
<td>55.56</td>
<td>69.24</td>
</tr>
<tr>
<td><strong>High demand</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>31.19</td>
<td>36.09</td>
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<td>52.87</td>
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<td></td>
<td>Emissions</td>
<td>180.23</td>
<td>208.80</td>
<td>231.46</td>
<td>262.64</td>
<td>296.85</td>
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<td>Allowance price</td>
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<td>32.09</td>
<td>34.91</td>
<td>37.98</td>
<td>41.33</td>
</tr>
<tr>
<td><strong>Nuclear case</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>31.94</td>
<td>37.64</td>
<td>45.77</td>
<td>49.63</td>
</tr>
<tr>
<td></td>
<td>Emissions</td>
<td>167.01</td>
<td>173.24</td>
<td>174.54</td>
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<td>44.25</td>
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<tr>
<td></td>
<td>Allowance price</td>
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<td>35.78</td>
<td>44.58</td>
<td>55.56</td>
<td>69.24</td>
</tr>
<tr>
<td><strong>PM expectations</strong></td>
<td>Electricity price</td>
<td>17.85</td>
<td>31.34</td>
<td>36.768</td>
<td>44.41</td>
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<tr>
<td></td>
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<td>174.54</td>
<td>192.65</td>
<td>194.67</td>
</tr>
<tr>
<td></td>
<td>Allowance price</td>
<td>n/a</td>
<td>34.24</td>
<td>42.66</td>
<td>53.17</td>
<td>66.25</td>
</tr>
</tbody>
</table>
It may be observed that with the introduction of CPRS, even with the low emission reduction target of 5% and low carbon prices, electricity price is rising (compare Base Case and Green Future). And the tendency is the next: the higher the carbon price, the higher electricity prices will be.

However, when the target is low, emissions do not start to decrease immediately. For instance, emissions in Green Future Scenario are equal to the ones in Base Case, and only at the end of the study period greenhouse gas emissions start to decrease. It means that carbon credits are not expensive enough to provoke generators to switch to the cleaner technologies. In 2030 carbon prices almost reach the 2020 level of Green Present scenario (with target of 25%).

An important role of demand can be observed from data that corresponds to High Demand scenario: electricity price is high as in the case with carbon prices higher than in the High Demand case. And emissions would considerably increase if the consumption were higher.

Another important observation is that support in Nuclear investments leads to the big and fast decrease in emission level at the low cost for electricity consumer.
Chapter 7. Conclusions.

This paper has presented a generation-expansion simulation model with the assumption on competitive market in electricity sector. The developed model takes into account environmental policies, such as Carbon Pollution Reduction Scheme that will be introduced in 2011 in Australia and Renewable Energy Targets. The main objective of the paper is to determine the influence of CPRS introduction on Australian electricity sector, taking into account its peculiarities and the existent regulation.

Performed simulation study differs in a positive way from other models with the similar objective:

- The electricity sector is modeled in great detail, in each state separately. This distinction makes the results of impact analysis more realistic. As far as electricity sector is the largest carbon dioxide emitter in the country (35% of total emissions), it will be affected mostly by the introduction of emission trading scheme. This is the reason why it is important to model it adequately.
- The developed model is a dynamic one: it simulates the capacity expansion in the country, creating a framework for future electricity, emission and REC markets.
- Linear model design makes possible to develop more detailed picture about the future. For instance, an input data – demand was introduced for each month for each load level.
- Three existent RET schemes are introduced in the model, two of them are state level targets and one – the national level one. REC prices are created endogenously in the model.
- Model takes into account the tendency in the international emission market development, introducing the emission allowances’ price exogenously.

Simulation results are reasonable and are in line with the other similar studies (performed by Climate Change Department of Australia and some consultant companies). Moreover, the study includes the deeply developed firms generation profiles, therefore it is provided the evolution of sector firm structure.

Simulation study determined that emission reduction target is one of the main factors affecting the policy’s effectiveness:

- The target of 5% is not enough to decrease the emissions during the study period. In the case that 5% emission reduction target is applied, 60% emission reduction commitment by 2050 will not be complied.
- The target of 25% lead to significant decrease in emissions and will favor in complying with the target 2050 of 60% reduction below 2000 level. However, it is too costly for the system: electricity prices will grow up in three times.

Another important factor is electricity demand growth. Even if high emission reduction target is imposed, emissions are likely to grow in the beginning. However, the generation mix is changing: all new generation that enters the market is represented by CCGT (with low emission rate) or by renewable technology.

Gas price can influence on the system only in the case of introduction of high emission reduction target. In other case coal remains the main generation technology and increase in gas price does not affect.
Performed scenario analysis demonstrates that elimination of the uncertainties in nuclear investments can become the least-cost solution for the Australian electricity sector. In this case nuclear will become the main generation technology and the emissions will be decreased in several times.

Introduction of the CPRS leads to the following:

- Electricity prices rise in 1.5-3 times, depending upon the scenario;
- REC's become cheaper and reach in some scenarios even price 0 (become useless because the electricity price is high enough to return the investments);
- Decrease in emissions according to the determined emission reduction target.

CPRS introduction is important to analyze in couple with other environmental policies (VRET, NRET, expanded MRET) introduced in Australia that can help to reduce high electricity price (caused by the CPRS introduction). In order to design a beneficial Scheme, RET should be determined correctly. Moreover, for the harmonious generation expansion, penalties under RET schemes should be changed. For instance, expanded MRET penalty should be higher than existent VRET and NRET penalties in order to promote not only intermittent wind but also base-load biotechnology.

The results of the study have both practical and theoretical value. The practical value of the study consists in the current model use in the company’s expansion strategy in Australian electricity market. Results of the simulation study are planned to publish in the near future.
Literature.


[ERNS08] Ernst&Young. Renewable energy country attractiveness indices. 2008.


Linares P., F. J. Santos, M. Ventosa, L. Lapiedra. Incorporating oligopoly, CO2 emission trading and green certificates into a power generation expansion model.


## Appendix 1. Generation by states.

### Queensland.

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Capacity, MW</th>
<th>Ownership</th>
<th>Ownership Structure</th>
<th>Type of Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gladstone</td>
<td>1680</td>
<td>Comalco, Transfield Services</td>
<td>62.5%, 37.5%</td>
<td>Coal</td>
</tr>
<tr>
<td>Stanwell</td>
<td>1440</td>
<td>Stanwell Corporation</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Tarong</td>
<td>1400</td>
<td>Tarong Energy</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Callide</td>
<td>900</td>
<td>CS Energy, Intergen</td>
<td>50%, 50%</td>
<td>Coal</td>
</tr>
<tr>
<td>Swanbank, B, E</td>
<td>865</td>
<td>CS Energy</td>
<td>100%</td>
<td>Coal/Gas</td>
</tr>
<tr>
<td>Millmerran</td>
<td>852</td>
<td>Intergen</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Kogan Creek</td>
<td>750</td>
<td>CS Energy</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Callide B</td>
<td>720</td>
<td>CS Energy</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Braemer</td>
<td>507</td>
<td>Babcock &amp; Brown Power</td>
<td>100%</td>
<td>Gas</td>
</tr>
<tr>
<td>Wivenhoe</td>
<td>500</td>
<td>Tarong Energy or Stanwell Corp</td>
<td>100%</td>
<td>Hydro</td>
</tr>
<tr>
<td>Tarong North</td>
<td>443</td>
<td>Tarong Energy, TEPCO/Mitsui &amp; Co</td>
<td>50%, 50%</td>
<td>Coal</td>
</tr>
<tr>
<td>Mica Creek</td>
<td>325</td>
<td>CS Energy</td>
<td>100%</td>
<td>Gas</td>
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<tr>
<td>Oakey</td>
<td>320</td>
<td>Babcock &amp; Brown Power, Contact Energy, ERM Power</td>
<td>50%, 25%, 25%</td>
<td>Gas</td>
</tr>
<tr>
<td>Mt Stuart</td>
<td>288</td>
<td>Origin Energy</td>
<td>100%</td>
<td>Gas</td>
</tr>
<tr>
<td>Yabulu</td>
<td>240</td>
<td>Transfield Services Infrastructure</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Townsville</td>
<td>220</td>
<td>Transfield Services Infrastructure</td>
<td>100%</td>
<td>Coal Steam Methane</td>
</tr>
<tr>
<td>Collingsville</td>
<td>180</td>
<td>Transfield Services Infrastructure</td>
<td>100%</td>
<td>Coal</td>
</tr>
<tr>
<td>Callide A</td>
<td>120</td>
<td>CS Energy</td>
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<td>Coal</td>
</tr>
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<td>Spring Gully</td>
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<td>Origin Energy</td>
<td>100%</td>
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<td>12</td>
<td>Transfield Services Infrastructure</td>
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<td>Wind</td>
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<td>Pioneer II</td>
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<td>CSR Sugar Mills</td>
<td>100%</td>
<td>Bagasse (Biogas)</td>
</tr>
<tr>
<td>Mulgrave</td>
<td>10.5</td>
<td>Independent Sugar North Ltd</td>
<td>100%</td>
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<td>Wind</td>
</tr>
<tr>
<td>Wingfield</td>
<td>16</td>
<td>Energy Developments Ltd</td>
<td>100%</td>
<td>Landfill Gas</td>
</tr>
</tbody>
</table>

**Comments.**

Bell Bay – the power plant will be retired.
Gordon – the power plant is in use.
Tamar Valley – the power plant is under construction.
Appendix 2. Existent and new technologies included in the model.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Conventional sign</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existent technologies</strong></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>FO</td>
</tr>
<tr>
<td>Open cycle gas turbine</td>
<td>GN</td>
</tr>
<tr>
<td>Combined cycle gas turbine</td>
<td>ECCGT</td>
</tr>
<tr>
<td>Coal</td>
<td>CI</td>
</tr>
<tr>
<td>Regulating hydro</td>
<td>REG</td>
</tr>
<tr>
<td>Run-of-the-river hydro</td>
<td>FLU</td>
</tr>
<tr>
<td>Pumping units</td>
<td>BOMB</td>
</tr>
<tr>
<td>Biomass</td>
<td>EBIO</td>
</tr>
<tr>
<td>Cogeneration</td>
<td>ECOG</td>
</tr>
<tr>
<td>Wind</td>
<td>EEOL</td>
</tr>
<tr>
<td>Coal Stem Gas</td>
<td>CSG</td>
</tr>
<tr>
<td><strong>New technologies</strong></td>
<td></td>
</tr>
<tr>
<td>Combined cycle gas turbine</td>
<td>CCGT</td>
</tr>
<tr>
<td>Supercritical coal</td>
<td>CSC</td>
</tr>
<tr>
<td>Advanced nuclear</td>
<td>NCLAV</td>
</tr>
<tr>
<td>Biomass: energy crop</td>
<td>BIO1</td>
</tr>
<tr>
<td>Biomass: landfill gas</td>
<td>BIO2</td>
</tr>
<tr>
<td>Wind</td>
<td>EOL</td>
</tr>
<tr>
<td>Off-shore wind</td>
<td>EOLOFF</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>SOLT</td>
</tr>
<tr>
<td>Solar photovoltaic</td>
<td>SOLFV</td>
</tr>
<tr>
<td>Cogeneration</td>
<td>COG</td>
</tr>
<tr>
<td>Coal Steam Gas</td>
<td>CSG</td>
</tr>
</tbody>
</table>
## Appendix 3. Parameters for existent power plants.

<table>
<thead>
<tr>
<th>State</th>
<th>Technology</th>
<th>Linear variable cost</th>
<th>Installed power</th>
<th>CO2 emission rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>QLD</td>
<td>CI-1</td>
<td>1591</td>
<td>9682</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>CSG-11</td>
<td>1548</td>
<td>1630</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>FO-1</td>
<td>4400</td>
<td>34</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>GN-1</td>
<td>5015</td>
<td>1288</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>GN-11</td>
<td>5015</td>
<td>1270</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>CCGT-1</td>
<td>3174</td>
<td>755</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>EBIO-1</td>
<td>5117</td>
<td>272.1</td>
<td>0</td>
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<tr>
<td></td>
<td>EEOL-1</td>
<td>0</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>VIC</td>
<td>CI-2</td>
<td>931</td>
<td>5117.2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>COG-2</td>
<td>3173</td>
<td>195</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>GN-2</td>
<td>5451</td>
<td>244</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>CCGT-2</td>
<td>3450</td>
<td>1799</td>
<td>0.37</td>
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<tr>
<td></td>
<td>CCGT-21</td>
<td>3450</td>
<td>1000</td>
<td>0.37</td>
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<tr>
<td></td>
<td>EBIO-2</td>
<td>5117</td>
<td>10.7</td>
<td>0</td>
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<td>EEOL-2</td>
<td>0</td>
<td>133.7</td>
<td>0</td>
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<tr>
<td></td>
<td>EEOL-21</td>
<td>0</td>
<td>483</td>
<td>0</td>
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<td></td>
<td>EEOL-22</td>
<td>0</td>
<td>334</td>
<td>0</td>
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<td></td>
<td>EEOL-23</td>
<td>0</td>
<td>614</td>
<td>0</td>
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<td>NSW</td>
<td>CI-3</td>
<td>1785</td>
<td>11751</td>
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<tr>
<td></td>
<td>COG-3</td>
<td>3236</td>
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<td></td>
<td>FO-3</td>
<td>4400</td>
<td>50</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>GN-3</td>
<td>5560</td>
<td>640</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>GN-31</td>
<td>5560</td>
<td>940</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>CCGT-3</td>
<td>3519</td>
<td>400</td>
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</tr>
<tr>
<td></td>
<td>CCGT-31</td>
<td>3519</td>
<td>1457</td>
<td>0.37</td>
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<td></td>
<td>EBIO-3</td>
<td>5117</td>
<td>128</td>
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<td>EEOL-3</td>
<td>0</td>
<td>15</td>
<td>0</td>
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<tr>
<td></td>
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<td>30</td>
<td>0</td>
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<tr>
<td></td>
<td>EEOL-32</td>
<td>0</td>
<td>66</td>
<td>0</td>
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<tr>
<td>TAS</td>
<td>GN-4</td>
<td>5633</td>
<td>380</td>
<td>0.79</td>
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<td>GN-40</td>
<td>5633</td>
<td>240</td>
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<td>EEOL-4</td>
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<td>EEOL-41</td>
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<td>SA</td>
<td>CI-5</td>
<td>2444</td>
<td>780</td>
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<td></td>
<td>COG-5</td>
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<td>189.4</td>
<td>0.8</td>
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<tr>
<td></td>
<td>GN-5</td>
<td>6105</td>
<td>356</td>
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<tr>
<td></td>
<td>CCGT-5</td>
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<td>2314</td>
<td>0.37</td>
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<tr>
<td></td>
<td>EBIO-5</td>
<td>5117</td>
<td>128</td>
<td>0</td>
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<td></td>
<td>EEOL-51</td>
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<td>57</td>
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</tr>
<tr>
<td></td>
<td>EEOL-52</td>
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<td>176.4</td>
<td>0</td>
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<tr>
<td></td>
<td>EEOL-53</td>
<td>0</td>
<td>400</td>
<td>0</td>
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</tbody>
</table>
### Appendix 4. Parameters for existent hydro power plants.

<table>
<thead>
<tr>
<th>State</th>
<th>REG</th>
<th>BOMB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Power (MW)</td>
<td>Annual Inflows (GWh)</td>
</tr>
<tr>
<td>QLD</td>
<td>157.7</td>
<td>348</td>
</tr>
<tr>
<td>VIC</td>
<td>665.1</td>
<td>978</td>
</tr>
<tr>
<td>NSW</td>
<td>2545.6</td>
<td>5525</td>
</tr>
<tr>
<td>TAS</td>
<td>2110.6</td>
<td>6194</td>
</tr>
</tbody>
</table>
Appendix 5. Parameters for new technologies.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Linear variable cost (cAud/MWh)</th>
<th>Investment cost (Aud/kW)</th>
<th>Maximum power (MW)</th>
<th>Use ratio</th>
<th>CO2 emission rate (tonne/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCGT</td>
<td>1940</td>
<td>109000</td>
<td>1</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>NCLAV</td>
<td>930</td>
<td>540000</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CSC</td>
<td>1800</td>
<td>310000</td>
<td>1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>COG</td>
<td>1455</td>
<td>110000</td>
<td>1315</td>
<td>0.426</td>
<td>0.63</td>
</tr>
<tr>
<td>BIO1</td>
<td>4515</td>
<td>260000</td>
<td>3000</td>
<td>0.799</td>
<td>0</td>
</tr>
<tr>
<td>BIO2</td>
<td>6000</td>
<td>280000</td>
<td>3000</td>
<td>0.799</td>
<td>0</td>
</tr>
<tr>
<td>MINH</td>
<td>0</td>
<td>360000</td>
<td>1000</td>
<td>0.267</td>
<td>0</td>
</tr>
<tr>
<td>EOL</td>
<td>0</td>
<td>260000</td>
<td>15000</td>
<td>0.300 – QLD 0.300 – VIC 0.340 – NSW 0.360 – TAS 0.350 – SA</td>
<td>0</td>
</tr>
<tr>
<td>EOLOFF</td>
<td>0</td>
<td>780000</td>
<td>30000</td>
<td>0.38</td>
<td>0</td>
</tr>
<tr>
<td>SOLT</td>
<td>0</td>
<td>590000</td>
<td>3500</td>
<td>0.109</td>
<td>0</td>
</tr>
</tbody>
</table>

$Title Modelo.
option iterlim = 1000000;
*Modelo RENOVABLES
*Australia
*Linear, transmission, no market power
*Next parameters are changed in InitInput.m...
*They are here to make possible running gams file without matlab (for testing purposes)
$setglobal FirstYear 2010
$setglobal LastYear 2031
$setglobal UseBonos 1
$setglobal UseRecs 1
$setglobal UseAtom 1
$setglobal UseFirstYears 1
$setglobal DemandDelta 0.02
$setglobal BonosPrice0 25
$setglobal BonosPriceDelta 0.017
$setglobal GasPriceKoef 1
$setglobal WindPmax 15000
$setglobal WindPercent1 0.3
$setglobal WindPercent2 0.5
$setglobal RecsPenaltyVRET 65
$setglobal RecsPenaltyMRET 300
$setglobal RecsPenaltyNRET 65
$setglobal MAXBANK 0
$setglobal ScaleBONOS 1
$setglobal ScaleRecs 1
$setglobal ScaleHydro 1
$setglobal ScalePCEcv 1
$setglobal ScalePCNcv 1
$setglobal ScalePCNci 1
$setglobal ScaleWINDci 1
$setglobal ScalePCEPmax 1
$setglobal ScalePCNPmax 1
$setglobal ScaleExport 1
$if exist matglobs.gms $include matglobs.gms
$setglobal NRETSstart %FirstYear%
$setglobal NRETSend %LastYear%
$setglobal VRETSstart %FirstYear%
$setglobal VRETSend %LastYear%
$setglobal MRETSstart %FirstYear%
$setglobal MRETSend %LastYear%

SETS
  e  states
  p  periodos
  s  subperiodos
  n  load levels
  ce  existent power stations
  h  hydro power stations
  f  run-of-river power stations
  b  pumping stations
  cn  new power stations
  tec  tecnologies
    GasTec(tec)  technologies that use gas as a fuel
    cats  technology categories
    recs  REC schemes
    atg  atributes of generators
cccem(e,ce) assigning of existent power station to states
chem(e,h) assigning of regulated power stations to states
chem(e,b) assigning of pumped-storage stations to state
cfem(e,f) assigning of run-of-river hydro stations to states
cetec(ce,tec) assigning of existent power stations to the technologies
chte(h,tec) assigning of hydro stations to the technologies
cfte(f,tec) assigning of run-of-river power stations to the technologies
cbte(b,tec) assigning of pumped-storage power stations to the technologies
cntec(cn,tec) assigning of new power stations to the technologies
tecats(tec,cats) technology categories assignments
NoInvest(p) There is no investments at these years!
ps(s) First subperiod
;
Alias(e,e1);
Alias(p,p1);
set
AliveCE(ce, p,p1) Money invested at year p still works at year p1
AliveCN(cn, p,p1) Money invested at year p still works at year p1
AliveBenene(p,p1) Money invested at year p still works at year p1
prevp(p,p1) previous year
BankAllowed(p,p1) Recs in year p1 can be banked till(used at) year p
;
VARIABLES
V_PCE(ce,p,s,n) Power generation by existent power stations
V_NSE(e,p,s,n) Non served energy
V_HH(h,p,s,n) Power generation by hydro technology
V_HB(b,p,s,n) Power generation by pumped-storage facilities
V_BB(b,p,s,n) Power energy consumed by pumped-storage facilities
V_R(h,p,s) Energy reserve level of each dam
VA_EXP(e,e1,p,s,n) export from the state e to the state e1
V_BONOSCE(p, ce) EA bought by existent power plants
V_BONOSCN(p, e, cn) EA bought by new power plants
V_RECSFAIL(recs, p) REC certificates not surrounded
V_RECSBANKED(recs, p) REC certificates banked
;
POSITIVE VARIABLES VA_EXP, V_PCE, V_HH, V_HB, V_BB, V_R, V_BONOSCE,
V_BONOSCN, V_RECSFAIL, V_RECSBANKED;
SETS
e /QLD, VIC, NSW, TAS, SA/
p /%FirstYear%*%LastYear%/
*s sets for power plants installation/retirement known by now
Closing09(p) /%FirstYear%*%LastYear%/
Opening11(p) /%FirstYear%*2010/
s /s1*s12/
n /n1*n5/
atg /coste, cv, cv2, Pmin, Pmax, Pmaxult, Rini, cin, tcOE, SO2, NOx, PART, rend, kc,
prima, RO,IsGreen/
tecc /CI, FO, GN, ECCGT, EBIO, EEO, REG, FLU, BOMB, ECOG,
CCGT, NCLAV, CSC, CSG, BIO1, BIO2, COG, MINH, EOL, EOLOFF, SOLT/
cats /GREEN, OIL, GAS, COAL, NUCLEAR, HYDRO/
tecats /CICOAL, FO.OIL, GN.GAS, ECCGT.GAS, EBIO.GREEN, EEO.GREEN, REG.HYDRO, FLU.HYDRO, BOMB.HYDRO, ECOG.GAS,
CCGT.GAS, NCLAV.NUCLEAR, CSC.COAL, CSG.COAL, BIO1.GREEN,
BIO2.GREEN,
COG.GAS, MINH.HYDRO, EOL.GREEN, EOLOFF.GREEN, SOLT.GREEN/

*Power Stations

ce

h

f
/FLU-5/

b
/BOMB-1, BOMB-3*BOMB-4/

cn
/CCGT, NCLAV, CSC, CSG, BIO1, BIO2, COG, MINH, EOL, EOLOFF, SOLT/

*Assignments

ceem

chem
/QLD.REG-1, VIC.REG-2, VIC.REG-21, NSW.REG-3, NSW.REG-31, TAS.REG-4/

cbem
/QLD.BOMB-1, NSW.BOMB-3/

cfem
/SA.FLU-5/

cetec

cbtec

cftec
/FLU-5.FLU/

cbtec
/BOMB-1.BOMB, BOMB-3.BOMB/
cntec  /CCGT,CCGT, NCLAV,NCLAV, CSC,CSC, CSG,CSG, BIO1,BIO1, BIO2.BIO2, COG.COG, MINH,MINH, EOL,EOL, EOLOFF,EOLOFF, SOLT,SOLT/
NoInvest(p)  /%FirstYear%*2013/

scalars
LifeBene return on investments expected in 15 years  /15/
ejeco2 execution with CO2 emission constrain  /%UseBonos%/
ejecrecs execution with REC  /%UseRecs%/
ejecNCLAV execution with Nuclear investment possibility  /%UseAtom%/
ejecFirstYears execution with fixed price for the 1st year  /%UseFirstYears%/
FirstBankYear first year with the possibility to bank the EA;

parameters
LifeCN(cn)
LifeCE(ce)

ps(s)=YES$(ORD(s)=1);
prevp(p,p1) = YES$(ORD(p)=ORD(p1)+1);

*no time limitation for use of existent and new technologies
LifeCE(ce)=100;
LifeCN(cn)=100;

*no time limitation for use of new wind power plants
LifeCN('EOL')=200;
LifeCN('EOLOFF')=200;
AliveCN(cn, p,p1)=YES$
  ( (ORD(p1) >= ORD(p))
   AND
   (ORD(p1)<=ORD(p)+LifeCN(cn)-1)
  );
AliveCE(ce, p, p1)=YES$
  ( (ORD(p1) >= ORD(p))
   AND
   (ORD(p1)<=ORD(p)+LifeCE(ce)-1)
  );
AliveBene(p, p1)=YES$
  ( (ORD(p1) >= ORD(p))
   AND
   (ORD(p1)<=ORD(p)+LifeBene-1)
  );

*AliveBene(p,p1)=YES$(ORD(p)=ORD(p1));
*Certificates can be banked starting from the first year of CPRS in use (second year of study period)
*Certificates can be banked starting from the second year of CPRS in use (from third year from the start of study period)
FirstBankYear = (3$ejecFirstYears)+(2$(NOT ejecFirstYears));
BankAllowed(p,p1)=YES$((ord(p1)=ord(p)) OR
((ord(p)>=FirstBankYear)AND(ord(p1)>=FirstBankYear)AND(ord(p)>=ord(p1))));
GasTec(tec)=YES$(teccats(tec, 'GAS'));

SCALARS
rend efficiency of pumping stations  /0.7/
rent WACC  /0.07/
crec demand growth  /%DemandDelta%/
kc coefficient of energy lost in transmission lines  /1/
khc hydrological coefficient  /1/
disp availability  /0.00/
MAX_BORROW  maximum borrowing rate  /0.05/
NSECost  Non Served Energy Cost  /10000/
ScaleBONOS  %ScaleBONOS%/
ScaleRecs  %ScaleRecs%/
ScaleHydro  %ScaleHydro%/
ScalePCEcv  %ScalePCEcv%/
ScalePCNcv  %ScalePCNcv%/
ScalePCNci  %ScalePCNci%/
ScaleWINDci  %ScaleWINDci%/
ScalePCEPmax  %ScalePCEPmax%/
WindPmax  %WindPmax%/
ScalePCNPmax  %ScalePCNPmax%/
ScaleExport  %ScaleExport%
;
PARAMETERS
dce(ce,atg)  attributes of existent generators that participate in the market
dcn(cn,atg)  attributes of new gene
tp(p)  tasa de actualizacion del valor del dinero por periodo
d(s,n)
Pini(e,s,n)
pi0(e,s,n)
WindPercent(e)
;
WindPercent('QLD')=%WindPercent1%;
WindPercent('VIC')=%WindPercent1%;
WindPercent('NSW')=%WindPercent2%;
WindPercent('TAS')=%WindPercent2%;
WindPercent('SA')=%WindPercent1%;

PARAMETERS
PB0  %BonosPrice0%/  
PBexp  %BonosPriceDelta%/  
PRECIOBONOext(p)  EA price on international market

*That's fix for last CPRC changes (price(2011)=10...))
*This is EA price for all scenarios except the last one
PRECIOBONOextOld(p)  Precio del permiso de emision externo
*This is EA price for last scenario (with last scheme changes)
PRECIOBONOextNew(p) Precio del permiso de emision externo
;
PRECIOBONOextNew(p)=(PB0 * (1 + PBexp)**(ORD(p)-3)*ScaleBONOS)$\text{(ejeccco2)};
PRECIOBONOextNew(2011)=10;
PRECIOBONOextOld(p)=(PB0 * (1 + PBexp)**(ORD(p)-2)*ScaleBONOS)$\text{(ejeccco2)};
*Here we sum both prices: depending on flag ejecFirstYears result will be equal PRECIOBONOextNew or PRECIOBONOextOld
PRECIOBONOext(p)=(PRECIOBONOextOld(p)$\text{(NOT ejecFirstYears)}+(PRECIOBONOextNew(p)$\text{(ejecFirstYears)};
PRECIOBONOext('2010')=0;

*Demand curve data 2007~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

TABLE
d(s,n)
n1  n2  n3  n4  n5
s1  225.0  262.5  112.5  102.0  42.0
s2  216.0  240.0  120.0  066.0  30.0
s3  310.5  216.0  121.5  066.0  30.0
s4  241.5  178.5  084.0  153.0  63.0
s5  67.5  472.5  108.0  66.0  30.0
s6  91.0  429.0  104.0  66.0  30.0
s7  143.0  377.0  104.0  82.5  37.5
s8  162.0  378.0  108.0  66.0  30.0
s9  162.5  337.5  100.0  85.0  35.0
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<th>202.5</th>
<th>108.0</th>
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<tr>
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<td>312.0</td>
<td>221.0</td>
<td>091.0</td>
<td>70.0</td>
<td>26.0</td>
<td></td>
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<tr>
<td>s12</td>
<td>240.0</td>
<td>228.0</td>
<td>108.0</td>
<td>122.5</td>
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</table>

* ~~~~~~~~~~~~ demand ~~~~~~~~~~~~ *

**TABLE**
Pini_NSW(s,n)

<table>
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<tr>
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<th>n4</th>
<th>n5</th>
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<tr>
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<td>8868.19</td>
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<tr>
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<td>6934.57</td>
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<td>10217.45</td>
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**TABLE**
Pini_QLD(s,n)

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<td>4582.94</td>
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<td>6776.83</td>
<td>6020.72</td>
<td>4626.92</td>
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<td>5976.60</td>
<td>4733.37</td>
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**TABLE**
Pini_SA(s,n)

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<th>n5</th>
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<td>1601.12</td>
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<td>1150.57</td>
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<td>1465.10</td>
<td>1064.43</td>
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<td>1743.47</td>
<td>1251.82</td>
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<td>1097.41</td>
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<td>1111.38</td>
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<td>1083.47</td>
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<tr>
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**TABLE**
Pini_TAS(s,n)

<table>
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<th>n4</th>
<th>n5</th>
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</thead>
<tbody>
<tr>
<td>s1</td>
<td>1144.05</td>
<td>1070.69</td>
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<td>1039.30</td>
<td>927.94</td>
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<tr>
<td>s2</td>
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<td>1095.83</td>
<td>958.14</td>
<td>1071.77</td>
<td>934.95</td>
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<tr>
<td>s3</td>
<td>1166.84</td>
<td>1069.17</td>
<td>954.61</td>
<td>1087.25</td>
<td>956.27</td>
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<tr>
<td>s4</td>
<td>1230.61</td>
<td>1081.82</td>
<td>956.42</td>
<td>1121.29</td>
<td>961.65</td>
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</table>
### TABLE Pini_VIC(s,n)

<table>
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<th>n4</th>
<th>n5</th>
</tr>
</thead>
<tbody>
<tr>
<td>s1</td>
<td>6758.60</td>
<td>5810.29</td>
<td>4891.61</td>
<td>5115.72</td>
</tr>
<tr>
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<td>6137.09</td>
<td>5090.72</td>
<td>5945.63</td>
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<tr>
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<td>6492.31</td>
<td>5631.78</td>
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<td>5227.65</td>
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<tr>
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<td>5630.12</td>
<td>4793.53</td>
<td>5183.84</td>
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</table>

*Joint all in one variable Pini*

\[
Pini('NSW', s, n) = Pini_NSW(s, n); \\
Pini('QLD', s, n) = Pini_QLD(s, n); \\
Pini('SA', s, n) = Pini_SA(s, n); \\
Pini('TAS', s, n) = Pini_TAS(s, n); \\
Pini('VIC', s, n) = Pini_VIC(s, n);
\]

### TABLE MAXLINE0(e,e1) maximum energy can be transmitted from state e to state e1

<table>
<thead>
<tr>
<th>QLD</th>
<th>VIC</th>
<th>NSW</th>
<th>TAS</th>
<th>SA</th>
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</thead>
<tbody>
<tr>
<td>QLD</td>
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<td>0</td>
<td>1078</td>
<td>0</td>
</tr>
<tr>
<td>VIC</td>
<td>0</td>
<td>0</td>
<td>1313</td>
<td>480</td>
</tr>
<tr>
<td>NSW</td>
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<td>1842</td>
<td>0</td>
<td>0</td>
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<td>600</td>
<td>0</td>
<td>0</td>
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<tr>
<td>SA</td>
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<td>514</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>

### PARAMETERS

MAXLINE(p,e,e1) maximum line capacity data is based on the empiric data from nemmco.au (year2008);

*assumption that transmission lines are groing as demand

\[
MAXLINE(p,e,e1) = MAXLINE0(e,e1) \times (1 + crec)^{(ORD(p)-1+3)};
\]

### TABLE dcesinrecs(ce,atg) data for thermalpower stations

<table>
<thead>
<tr>
<th>coste</th>
<th>cv</th>
<th>cv2</th>
<th>Pmin</th>
<th>Pmax</th>
<th>teCO</th>
<th>SO2</th>
<th>NOx</th>
<th>PART</th>
<th>prima</th>
</tr>
</thead>
<tbody>
<tr>
<td>cAu/Mcal</td>
<td>Mcal/MWh</td>
<td>Mcal/MW2h</td>
<td>MW</td>
<td>MW</td>
<td>t/MWh</td>
<td>g/kWh</td>
<td>g/kWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p.u.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI-1</td>
<td>0.41</td>
<td>3880</td>
<td>0</td>
<td>0</td>
<td>9682</td>
<td>0.90</td>
<td>2.65</td>
<td>2.23</td>
<td>0.15</td>
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<tr>
<td>CI-2</td>
<td>0.24</td>
<td>3880</td>
<td>0</td>
<td>0</td>
<td>5117.2</td>
<td>0.90</td>
<td>2.65</td>
<td>2.23</td>
<td>0.15</td>
</tr>
<tr>
<td>CI-3</td>
<td>0.46</td>
<td>3880</td>
<td>0</td>
<td>0</td>
<td>11751</td>
<td>0.90</td>
<td>2.65</td>
<td>2.23</td>
<td>0.15</td>
</tr>
<tr>
<td>CI-5</td>
<td>0.63</td>
<td>3880</td>
<td>0</td>
<td>0</td>
<td>780</td>
<td>0.90</td>
<td>2.65</td>
<td>2.23</td>
<td>0.15</td>
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</table>

| CSG-11 | 0.6 | 2580 | 0 | 0 | 1630 | 0.80 | 0.2 | 0.3 | 0.2 | 0 | 1 |
| COG-2 | 1.5 | 2115 | 0 | 0 | 195 | 0.80 | 0.2 | 0.3 | 0.2 | 0 | 1 |
| COG-3 | 1.53 | 2115 | 0 | 0 | 224 | 0.80 | 0.2 | 0.3 | 0.2 | 0 | 1 |
### TABLE

<table>
<thead>
<tr>
<th>RO</th>
<th>cAu/Mcal</th>
<th>Mcal/MWh</th>
<th>Mcal/MW2h</th>
<th>MW</th>
<th>MW</th>
<th>t/MWh</th>
<th>g/kWh</th>
<th>g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>0</td>
<td>483</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.34</td>
</tr>
<tr>
<td>EEOL-22</td>
<td>1.1</td>
<td>0</td>
<td>0</td>
<td>334</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.34</td>
</tr>
<tr>
<td>EEOL-23</td>
<td>1.1</td>
<td>0</td>
<td>0</td>
<td>614</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.34</td>
</tr>
<tr>
<td>EEOL-31</td>
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<td>0</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.30</td>
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<td>EEOL-32</td>
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<td>0</td>
<td>66</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.30</td>
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<tr>
<td>EEOL-41</td>
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<td>0</td>
<td>129</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.36</td>
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<td>0</td>
<td>57</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.35</td>
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<tr>
<td>EEOL-52</td>
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<td>0</td>
<td>0</td>
<td>176.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.35</td>
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<tr>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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### TABLE

<table>
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<th>dh(h,atg)</th>
<th>hydro power plant data</th>
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<td>Pmin</td>
<td>Pmax</td>
</tr>
<tr>
<td>MW</td>
<td>MW</td>
</tr>
<tr>
<td>REG-1</td>
<td>0</td>
</tr>
<tr>
<td>REG-2</td>
<td>0</td>
</tr>
<tr>
<td>REG-21</td>
<td>0</td>
</tr>
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<td>REG-3</td>
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</tr>
<tr>
<td>REG-31</td>
<td>0</td>
</tr>
<tr>
<td>REG-4</td>
<td>0</td>
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</table>

*HYDRO POWER PLANT DATA*
\( \text{dh}(h,'Rmax') = \text{dh}(h,'Rmax') \times 1e3; \)
\( \text{dh}(h,'Rini') = \text{dh}(h,'Rini') \times 1e3; \)

**TABLE**

\[
\begin{array}{cccccccccccc}
\text{A}(h,s) & \text{each dam inflow} \\
\hline
s1 & s2 & s3 & s4 & s5 & s6 & s7 & s8 & s9 & s10 & s11 & s12 \\
\hline
\text{REG-1} & 12 & 15 & 17 & 40 & 13 & 29 & 26 & 54 & 107 & 150 & 242 & 178 & 100 \\
\text{REG-2} & 36 & 7 & 7 & 28 & 50 & 64 & 107 & 150 & 242 & 178 & 100 & 586 \\
\text{REG-21} & 7 & 1 & 1 & 1 & 5 & 10 & 13 & 22 & 31 & 50 & 37 & 21 \\
\text{REG-3} & 209 & 42 & 42 & 42 & 167 & 293 & 377 & 628 & 879 & 1423 & 1046 & 586 \\
\text{REG-31} & 7 & 1 & 1 & 1 & 5 & 10 & 13 & 22 & 31 & 50 & 37 & 21 \\
\text{REG-4} & 245 & 215 & 215 & 440 & 620 & 687 & 825 & 832 & 735 & 609 & 439 & 332 \\
\end{array}
\]

*scaling: GWh->MWh
\( \text{A}(h,s) = \text{A}(h,s) \times 1e3; \)

**TABLE**

\[
\begin{array}{cccc}
\text{db}(b,\text{atg}) & \text{pumping station data} \\
\hline
\text{Pmin} & \text{Pmax} & \text{Rmax} \\
\hline
\text{BOMB-1} & 0 & 500 & 90 \\
\text{BOMB-3} & 0 & 1660 & 500 \\
\text{BOMB-4} & 0 & 300 & 90 \\
\end{array}
\]

*scaling: GWh->MWh
\( \text{db}(b,'Rmax') = \text{db}(b,'Rmax') \times 1e3; \)

**TABLE**

\[
\begin{array}{ccccccccccccccc}
\text{fluy}(f,s) & \text{run-of-river data (MW)} \\
\hline&s1 & s2 & s3 & s4 & s5 & s6 & s7 & s8 & s9 & s10 & s11 & s12 \\
\hline
\text{FLU-5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{array}
\]

**TABLE**

\[
\begin{array}{cccccccccccccccccccc}
\text{dcnrecs}(cn,\text{atg}) & \text{new power plants data} \\
\hline
\text{coste} & \text{cv} & \text{cv2} & \text{cin} & \text{teCO} & \text{SO2} & \text{NOx} & \text{PART} & \text{prima} & \text{Pmax} & \text{Pmaxult} & \text{RO} \\
\hline
\text{CCGT} & 1 & 1940 & 0 & 109000 & 0.37 & 0.007 & 1.2 & 0.02 & 0 & INF & INF & 0.426 \\
\text{NCLAV} & 1 & 930 & 0 & 540000 & 0.2 & 0.007 & 1.2 & 0.02 & 0 & INF & INF & 0.426 \\
\text{CSC} & 1 & 1800 & 0 & 310000 & 0.2 & 0.007 & 1.2 & 0.02 & 0 & INF & INF & 0.426 \\
\text{COG} & 1 & 1455 & 0 & 110000 & 0.63 & 0.2 & 0.3 & 0.2 & 0 & INF & INF & 0.426 \\
\end{array}
\]

*MINH-minihydro
*SOLT-solar thermal
*SOLFV-solar foto voltaica
*BIO1-energy crop-sugarane etc...->gasification technology applied
*BIO2-landfill gas->Stirling Cycle engine is applie
\( \text{dcnrecs}(cn,\text{atg}) \) datos centrales nuevas

**TABLE**

\[
\begin{array}{cccccccccccccccccccc}
\text{dcnrecs}(cn,\text{atg}) & \text{datos centrales nuevas} \\
\hline
\text{coste} & \text{cv} & \text{cv2} & \text{cin} & \text{teCO} & \text{SO2} & \text{NOx} & \text{PART} & \text{prima} & \text{Pmax}
\end{array}
\]

Pmaxult \( \text{RO} \)
<table>
<thead>
<tr>
<th></th>
<th>cAu/Mcal</th>
<th>Mcal/MWh</th>
<th>Mcal/MW2h</th>
<th>cAu/kW</th>
<th>t/MWh</th>
<th>g/kWh</th>
<th>g/kWh</th>
<th>g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.799</td>
<td>BIO1</td>
<td>1</td>
<td>4515</td>
<td>0</td>
<td>260000</td>
<td>1.2</td>
<td>0.3</td>
<td>0.35</td>
</tr>
<tr>
<td>0.799</td>
<td>BIO2</td>
<td>1</td>
<td>6000</td>
<td>0</td>
<td>280000</td>
<td>1.2</td>
<td>0.3</td>
<td>0.35</td>
</tr>
<tr>
<td>0.267</td>
<td>MINH</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>360000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.300</td>
<td>EOL</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>260000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.380</td>
<td>EOLOFF</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>780000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.109</td>
<td>SOLT</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>590000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

```
; dcerecs(ce, 'IsGreen')=1$(dcerecs(ce, 'Pmax')>0);
dcnrecs(cn, 'IsGreen')=1$(dcnrecs(cn, 'Pmax')>0);
dce(ce,atg) =dcesinrecs(ce,atg)+dcerecs(ce,atg);
dcn(cn,atg) =dcnsinrecs(cn,atg)+dcnrecs(cn,atg);
dcn(cn,'cin')=dcn(cn,'cin')*10;
dce(ce,'cv')=dce(ce,'cv')*ScalePCEcv;
dcn(cn,'cv')=dcn(cn,'cv')*ScalePCNcv;
dce(ce,'coste')=dce(ce,'coste')/100;
dcn(cn,'coste')=dcn(cn,'coste')/100;

parameter GasPrice(e);
GasPrice('QLD')=1.38;
GasPrice('VIC')=1.5;
GasPrice('NSW')=1.53;
GasPrice('TAS')=1.55;
GasPrice('SA')=1.68;

parameter CNCOSTE(e,cn) Take gas price into account;
CNCOSTE(e,cn)=dcn(cn,'coste');

loop(tec,
CNCOSTE(e,cn)$ (GasTec(tec)AND cntec(cn, tec)) = dcn(cn,'coste')*GasPrice(e)*%GasPriceKoef%)
);

*Let's take gas price delta into account for CE
loop(e,
    loop(tec,
    dce(ce,'coste')$ (GasTec(tec)AND cetec(ce, tec) AND (cceeem(e,ce))) = dce(ce,'coste')*%GasPriceKoef%);

    display CNCOSTE;
    dcn(cn,'cin')=dcn(cn,'cin')*ScalePCNci;
dcn('EOL','cin')=dcn('EOL','cin')*ScaleWINDci;
dce(ce,'Pmax')=dce(ce,'Pmax')*ScalePCEPmax;
dcn(cn,'Pmax')=dcn(cn,'Pmax')*ScalePCNmax;
dcn(cn,'Pmaxult')=dcn(cn,'Pmaxult')*ScalePCNmax;

*RO parameter for state e
parameter RO(e,cn);
RO(e,cn)=dcn(cn,'RO');

*RO data for different states:
RO('QLD','EOL')=0.30;
RO('NSW','EOL')=0.34;
RO('VIC','EOL')=0.30;
RO('TAS','EOL')=0.36;
RO('SA','EOL')=0.35;
```

sets
recs /NRET, VRET, MRET/
NRETyears(p) /%NRETstart%*%NRETend%/
VRETyears(p) /%VRETstart%*%VRETend%/
MRETyears(p) /%MRETstart%*%MRETend%/
VRETestados(e) /VIC/
NRETestados(e) /NSW, QLD, VIC/
MRETestados(e) /NSW, QLD, VIC, TAS, SA/
recsequ /forVRET, forNRET, forMRET/
UseForVRET(recs) /VRET/
UseForNRET(recs) /VRET, NRET/
UseForMRET(recs) /VRET, NRET, MRET/
*recs by state (YES/NO)
erecs(e, recs)
*recs by year (YES/NO)
precs(p, recs)
UseRecs(recsequ, recs)

TABLE
RecsLimit(recs, p)

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NRET</td>
<td>1317</td>
<td>1910</td>
<td>2504</td>
<td>3097</td>
<td>3690</td>
<td>4284</td>
<td>4877</td>
<td>5470</td>
<td>6063</td>
<td>6657</td>
<td>7250</td>
<td>7250</td>
<td>7250</td>
</tr>
<tr>
<td>VRET</td>
<td>963</td>
<td>1348</td>
<td>1733</td>
<td>2118</td>
<td>2504</td>
<td>2889</td>
<td>3274</td>
<td>3274</td>
<td>3274</td>
<td>3274</td>
<td>3274</td>
<td>3274</td>
<td>3274</td>
</tr>
<tr>
<td>MRET</td>
<td>12500</td>
<td>14400</td>
<td>16300</td>
<td>18200</td>
<td>20100</td>
<td>22000</td>
<td>26600</td>
<td>31200</td>
<td>35800</td>
<td>40400</td>
<td>45000</td>
<td>45000</td>
<td>45000</td>
</tr>
</tbody>
</table>

RecsLimit(recs, p)$(ord(p)>(2030-%FirstYear%+1))=RecsLimit(recs, '2030');

parameter
RecsPenalty(recs)

RecsPenalty('NRET')=%RecsPenaltyNRET%;
RecsPenalty('VRET')=%RecsPenaltyVRET%;
RecsPenalty('MRET')=%RecsPenaltyMRET%;
SCALAR
MAXBANK /%MaxBank%/

RecsLimit(recs, p)=RecsLimit(recs, p)*1000*ScaleRecs;

*Sets of green tecnologies
SETS
GreenCN(cn),
GreenCE(ce);

GreenCE(ce)=YES$(dcrecs(ce, 'Pmax')>0);
GreenCN(cn)=YES$(dcrecs(cn, 'Pmax')>0);
*installation of new power plants/retire the old ones
V_PCE.fx('CCGT-21',Opening11(p),s,n) = 0;
V_PCE.fx('EEOL-23',Opening11(p),s,n) = 0;
V_PCE.fx('GN-31',Opening11(p),s,n) = 0;
V_PCE.fx('EEOL-32',Opening11(p),s,n) = 0;
V_PCE.fx('GN-40',Closing09(p),s,n) = 0;
V_PCE.fx('EEOL-53',Opening11(p),s,n) = 0;
V_PCE.up(ce,p,s,n) = dce(ce,'Pmax') * dce(ce,'RO');
V_PCE.lo(ce,p,s,n) = dce(ce,'Pmin');
V_HH.up(h,p,s,n) = dh(h,'Pmax')*ScaleHydro;
V_HH.lo(h,p,s,n) = dh(h,'Pmin');
V_BB.up(b,p,s,n) = db(b,'Pmax');
V_HB.up(b,p,s,n) = db(b,'Pmax');
V_R.up(h,p,s) = dh(h,'Rmax');
V_R.fx(h,p,ps) = dh(h,'Rini');
VA_EXP.up(e,e1,p,s,n) = MAXLINE(p,e,e1);

VARIABLE
  V_Coste
  V_PCNpi(e,cn,p,s,n)
  V_Invest(e,cn,p)
  V_Ipi(e,cn,p);
positive variables V_Ipi, V_PCNpi, V_NSE, V_Invest(e,cn,p);  
V_Ipi.fx(e,'NCLAV',p)$(NOT ejecNCLAV) = 0;
V_RECSBANKED.up(recs,p) = RecsLimit(recs,p)*0.1;
V_Invest.up(e, cn, p)=dcn(cn,'Pmaxult');

EQUATIONS
  E_Coste
  E_DEM(e, p,s,n)
  ER_PCNpi(e,cn,p,s,n)
  ER_Ipi(e,cn,p)
  ER_IPLANultpi(cn)
  ER_EH(h,p,s)
  ER_BOMB(b,p,s)
  ER_EBOMBMAX(b,p,s)
  ER_TOPECOMTAM(p)
  E_BONOSCE(p, ce)
  E_BONOSCN(p, e, cn)
  E_RECSLIMIT_VRET(p)
  E_RECSLIMIT_NRET(p)
  E_RECSLIMIT_MRET(p)
  E_EOL(p)
  E_EOLPERCENT(e,p,s,n)

  ER_EH(h,p,s) ..
    SUM(n, d(s,n) * SUM(e$chem(e,h), V_HH(h,p,s,n))) - V_R(h,p,s) + V_R(h,p,s+1)$ORD(s) LT CARD(s)) -
    A(h,s)*ScaleHydro + dh[h,'Rini']$ORD(s) EQ CARD(s))
    =l= 0;
  ER_BOMB(b,p,s) ..
    SUM(n, d(s,n) * (SUM(e$cbem(e,b),V_BB(b,p,s,n)) - SUM(e$cbem(e,b),V_HB(b,p,s,n)) *
      rend))
    =l= 0;
  ER_EBOMBMAX(b,p,s) ..
    SUM(n, d(s,n) * SUM(e$cbem(e,b),V_BB(b,p,s,n))) - db(b,'Rmax')
    =l= 0;
  E_Coste ..
  V_Coste =E=
SUM((ce,p,s,n), tp(p) * d(s,n) * (dce(ce,'coste') * dce(ce,'cv') - dce(ce,'prima')) * V_PCE(ce,p,s,n))
+ SUM((e,cn,p,s,n), tp(p) * d(s,n) * (dcn(cn,'cv') * CNCOST(e, cn) - dcn(cn,'prima')) * V_PCNpi(p,e,cn,p,s,n))
+ SUM((p, ce)$(ejecco2), tp(p) * V_BONOSCE(p, ce)*PRECIOBONOext(p))
+ SUM((e, cn,p,s,n)$(ejecco2), tp(p) * V_BONOSCN(p, e, cn)*PRECIOBONOext(p))
+ SUM((e,cn,p), dcn(cn,'cin') * tp(p) * (V_Invest(e,cn,p)))
+ SUM((recs,p),tp(p) * RecsPenalty(recs)*V_RECSFAIL(recs, p))
+
SUM((e,cn,p,s,n), tp(p) * V_PCE(ce,p,s,n))
+ SUM(h$chem(e,h), V_HH(h,p,s,n))
+ SUM(cn, V_PCNpi(e,cn,p,s,n))
+ SUM(b$cbem(e,b), V_BB(b,p,s,n))
- SUM(b$cbem(e,b), V_HB(b,p,s,n))
+ SUM(f$cfem(e,f), fluy(f,s))
* V_NSE(e,p,s,n)
- Pini(e,s,n) * (1 + crec)**(ORD(p)-1+3)
*less export
- SUM(e1,VA_EXP(e,e1,p,s,n))
*more import
+ SUM(e1,VA_EXP(e1,e,p,s,n))
= 0;

E_DEM(e, p,s,n)..  
SUM(ce$cceem(e,ce), V_PCE(ce,p,s,n))
+ SUM(h$chem(e,h), V_HH(h,p,s,n))
+ SUM(cn, V_PCNpi(e,cn,p,s,n))
+ SUM(b$cbem(e,b), V_BB(b,p,s,n))
- SUM(b$cbem(e,b), V_HB(b,p,s,n))
+ SUM(f$cfem(e,f), fluy(f,s))
* V_NSE(e,p,s,n)
- Pini(e,s,n) * (1 + crec)**(ORD(p)-1+3)
*less export
- SUM(e1,VA_EXP(e,e1,p,s,n))
*more import
+ SUM(e1,VA_EXP(e1,e,p,s,n))
= 0;

ER_PCNpi(e, cn,p,s,n) ..  
V_PCNpi(e, cn,p,s,n) - RO(e, cn)*V_Ipi(e, cn,p) = l= 0;

ER_Ipi(e, cn,p, p) ..  
V_Ipi(e, cn, p) =e= SUM((p1)$AliveCN(cn, p1,p), V_Invest(e, cn, p1));
V_Invest.up(e, cn, p)=dcn(cn,'Pmaxult');

*Equation for banking and borrowing (for CE)
E_BONOSCE(p, ce)..
*Sum of all bonos before year p
SUM(p1$((ejecco2)AND BankAllowed(p1,p))),
V_BONOSCE(p1, ce)
*MINUS
- *Sum of all contaminations before p
SUM((s,n), d(s,n) * dce(ce,'teCO') * V_PCE(ce,p1,s,n)))
*but plus 5% of year p contaminations (borrowing)
+ MAX_BORROW*
(SUM((s,n), d(s,n) * dce(ce,'teCO') * V_PCE(ce,p,s,n)))
*Must be greater then zero
= 0;

*Equation of banking and borrowing (for CN)
E_BONOSCN(p, e, cn) ..
*Sum of all bonos before year p
SUM(p1$((ejecco2)AND BankAllowed(p,p1))),
V_BONOSCN(p1, e, cn)
*MINUS
- *Sum of all contaminations before p
SUM((s,n), d(s,n) * dcn(cn,'teCO')*V_PCNpi(e,cn,p1,s,n)))
*but plus 5% of year p contaminations (borrowing)
+ MAX_BORROW*
(SUM((s,n), d(s,n) * dcn(cn,'teCO')*V_PCNpi(e,cn,p,s,n)))
*Must be greater then zero
= 0;

E_RECSLIMIT_VRET(p) ..
SUM((s,n,cn)$(GreenCN(cn) AND erecs(e, 'VRET')), d(s,n) * V_PCNpi(e, cn,p,s,n))
+SUM((s,n,ce)$(GreenCE(ce) AND erecs(e, 'VRET') AND cceem(e, ce)), d(s,n) * V_PCE(ce,p,s,n))
+SUM(p1$prevp(p,p1), V_RECSBANKED('VRET', p1))
-V_RECSBANKED('VRET', p)
+V_RECSFAIL('VRET', p)
-RecsLimit('VRET', p)

=g=0;
E_RECSLIMIT_NRET(p)..
    SUM((s,n,cn)$(GreenCN(cn) AND erecs(e, 'NRET')), d(s,n) * V_PCNpi(e, cn,p,s,n))
    +SUM((s,n,ce)$(GreenCE(ce) AND erecs(e, 'NRET') AND cceem(e, ce)), d(s,n) * V_PCE(ce,p,s,n))
    +SUM(p1$prevp(p,p1), V_RECSBANKED('NRET', p1))
    -V_RECSBANKED('NRET', p)
    +V_RECSFAIL('NRET', p)
    -RecsLimit('VRET', p)
    -RecsLimit('NRET', p)

=g=0;
E_RECSLIMIT_MRET(p)..
    SUM((s,n,cn)$(GreenCN(cn) AND erecs(e, 'MRET')), d(s,n) * V_PCNpi(e, cn,p,s,n))
    +SUM((s,n,ce)$(GreenCE(ce) AND erecs(e, 'MRET') AND cceem(e, ce)), d(s,n) * V_PCE(ce,p,s,n))
    +SUM(p1$prevp(p,p1), V_RECSBANKED('MRET', p1))
    -V_RECSBANKED('MRET', p)
    +V_RECSFAIL('MRET', p)
    -RecsLimit('VRET', p)
    -RecsLimit('NRET', p)
    -RecsLimit('MRET', p)

=g=0;
E_EOL(p)..
    SUM(e,V_Ipi(e,'EOL',p)) =l= WindPmax;
    E_EOLPERCENT(e,p,s,n)

*Sum of the wind energy produced
SUM(ce$(cceem(e,ce)AND cetec(ce,'EEOL')), V_PCE(ce,p,s,n))
+ SUM(cn$(cntec(cn,'EOL')), V_PCNpi(e,cn,p,s,n))
=1

*Sum of the total energy produced
WindPercent(e)*
(Pini(e,s,n) * (1 + crec)**(ORD(p)-1+3))

Model Puntoinicial
/E_Coste,
/ER_EH, ER_BOMB,
ER_EBOMBMAX,
ER_Ipi, ER_PCNpi,
E_DEM,
E_BONOSCE,
E_BONOSCN,
E_RECSLIMIT_VRET,
E_RECSLIMIT_NRET,
E_RECSLIMIT_MRET,
E_EOL/;

*in this poit appear MATLAB data
$if exist matdata.gms $include matdata.gms
option LP = CPLEX;
SOLVE Puntoinicial minimizing V_Coste using LP;
debugging output

parameter

EnergyVCE(p,e)
EnergyVCN(p,e)
EnergyDem(p,e)
EnergyHH(p,e)
EnergyHB(p,e)
EnergyBB(p,e)
SUMEXP(p,e)
SUMIMP(p,e)
RESCOSTM(p)
RESCOSTN(p)
RESCOSTV(p)
MEGACOST(e, p,s,n)
ENERGYBYTEC(tec,e,p,s,n)
ENERGYBYCAT(cats,e,p,s,n)
InstCapacity(e,tec,p)
InstCats(e,cats,p)
SumEmis(e,p)
BeneCE(e,tec,p)
BeneCN(e,cn,p)
BeneTec(e,tec,p)

EnergyDem(p,e)=SUM((s,n),Pini(e,s,n) * (1 + crec)**(ORD(p)-1)/1e3);
EnergyVCE(p,e)=SUM(ce$cceem(e,ce),
SUM((s,n),V_PCE.l(ce,p,s,n)));
EnergyVCN(p,e)=SUM((cn,s,n),V_PCNpi.l(e,cn,p,s,n));
EnergyHH(p,e)=SUM(h$chem(e,h),
SUM((s,n),V_HH.l(h,p,s,n)));
EnergyHB(p,e)=SUM(b$cbem(e,b),
SUM((s,n),V_HB.l(b,p,s,n)));
EnergyBB(p,e)=SUM(b$cbem(e,b),
SUM((s,n),V_BB.l(b,p,s,n)));
SUMEXP(p,e) = SUM((e1,s,n),VA_EXP.l(e,e1,p,s,n));
SUMIMP(p,e) = SUM((e1,s,n),VA_EXP.l(e1,e,p,s,n));
RESCOSTM(p) = SUM((p1)$(ORD(p1)=ORD(p)), E_RECSLIMIT_MRET.m(p1)/tp(p1));
RESCOSTV(p) = SUM((p1)$(ORD(p1)=ORD(p)), E_RECSLIMIT_VRET.m(p1)/tp(p1));
RESCOSTN(p) = SUM((p1)$(ORD(p1)=ORD(p)), E_RECSLIMIT_NRET.m(p1)/tp(p1));
MEGACOST(e, p,s,n)=0;
MEGACOST(e, p,s,n)$(E_DEM.m(e, p,s,n)>1) = E_DEM.m(e, p,s,n)/tp(p)/d(s,n);
ENERGYBYTEC(tec,e,p,s,n) =
SUM((ce)$((cetec(ce,tec)AND cceem(ce,ce)),V_PCE.l(ce,p,s,n)) +
SUM((h)$((chtceh,tec)AND chem(e,h)), V_HH.l(h,p,s,n)) +
SUM((f)$((cftec(f,tec)AND cfem(e,f)), fluy(f,s)) +
SUM((b)$((cbtec(b,tec)AND cbem(e,b)), V_BB.l(b,p,s,n)) +
SUM((cn)$((cntec(cn,tec)), V_PCNpi.l(e,cn,p,s,n));
ENERGYBYCAT(cats,e,p,s,n) =
SUM((tec)$((teccats(tec,cats)),ENERGYBYTEC(tec,e,p,s,n));
BeneCN(e, cn, p)$(V_Lpi.l(e,cn,p)>0)=
SUM((s,n),d(s,n)*V_PCNpi.l(e,cn,p,s,n)*
( MEGACOST(e, p,s,n)
-dcn(cn,'cv')*CNCOSTE(e,cn)

END
BeneCE(e, ce, p)$\{dce(ce,'Pmax')>0\} = SUM((s,n)\$cceem(e,ce),
     d(s,n)*V_PCE.l(ce,p,s,n)*
     (MEGACOST(e, p,s,n) -dce(ce,'coste')*dce(ce,'cv')
     -PRECIUBONOext(p)*dce(ce,'teCO')
     +RESCOSTM(p)$\{GreenCE(ce)\})
     )/dce(ce,'Pmax');
BeneCE(e, ce, p)$\{SUM((p1)$AliveBene(p,p1), 1)>0\} = SUM((p1)$AliveBene(p,p1), BeneCE(e, ce, p1)) / SUM((p1)$AliveBene(p,p1), 1); 
BeneCN(e, cn, p)$\{SUM((p1)$AliveBene(p,p1), 1)>0\} = SUM((p1)$AliveBene(p,p1), BeneCN(e, cn, p1)) / SUM((p1)$AliveBene(p,p1), 1) - (dcn(cn, 'cin'/LifeBene)$\{V_Ipi.l(e,cn,p)>0\})/;
BeneTec(e, tec, p) = (SUM((cn)$cntec(cn,tec),BeneCN(e, cn, p))/SUM((cn)$cntec(cn,tec),1)
)\{SUM((cn)$cntec(cn,tec),1)>0\} + (SUM((ce)$cetec(ce,tec),BeneCE(e, ce, p))/SUM((ce)$cetec(ce,tec),1)
)\{SUM((ce)$cetec(ce,tec),1)>0\};
InstCapacity(e,tec,p)=
     SUM((cn)$cntec(cn,tec),V_Ipi.l(e,cn,p))+
     SUM((ce)$cetec(ce,tec) AND cceem(e,ce)),dce(ce,'Pmax'));
InstCats(e,cats,p)=
     SUM((tec)$teccats(tec,cats)),InstCapacity(e,tec,p));
SumEmis(e,p)=
     SUM((cn,s,n),d(s,n)*V_PCNpi.l(e,cn,p,s,n)*dcn(cn,'teCO'))+
     SUM((ce,s,n)$cceem(ce,e),d(s,n)*V_PCE.l(ce,p,s,n)*dce(ce,'teCO'));
display MAXLINE0, V_Invest.l;
display V_PCE.l, Pini; 
display MEGACOST; 
display GreenCN, GreenCE; 
*end of debugging output
*sending data to Matlab 
Slibinclude matout ce 
Slibinclude matout cn 
Slibinclude matout e 
Slibinclude matout s 
Slibinclude matout n 
Slibinclude matout tec 
Slibinclude matout cats 
Slibinclude matout cceem e ce 
Slibinclude matout chem e h 
Slibinclude matout chem e b
$libinclude matout cfem e f
$libinclude matout cetec ce tec
$libinclude matout cntec cn tec
$libinclude matout d s n
$libinclude matout V_PCE.l ce p s n
$libinclude matout V_HH.l b p s n
$libinclude matout V_PCNpi.l e cn p s n
$libinclude matout V_Ipi.l e cn p
$libinclude matout V_R.l b p s
$libinclude matout V_HB.l b p s n
$libinclude matout V_BB.l b p s n
$libinclude matout VA_EXP.l e c1 p s n
$libinclude matout dce ce atg
$libinclude matout dcn cn atg
$libinclude matout PRECIOBONOext p
$libinclude matout V_BONOSCE.l p c e
$libinclude matout V_BONOSCN.l p e c n
$libinclude matout MEGACOST e p s n
$libinclude matout RECSFONSTN p
$libinclude matout RECSFONSTV p
$libinclude matout RECSFONSTM p
$libinclude matout ENERGYBYTEC tec e p s n
$libinclude matout ENERGYBYCAT cats e p s n
$libinclude matout V_Invest.l e c n p
$libinclude matout InstCapacity e tec p
$libinclude matout InstCats e cats p
$libinclude matout RecsLimit recs p
$libinclude matout SumEmis e p
$libinclude matout BeneTec e tec p