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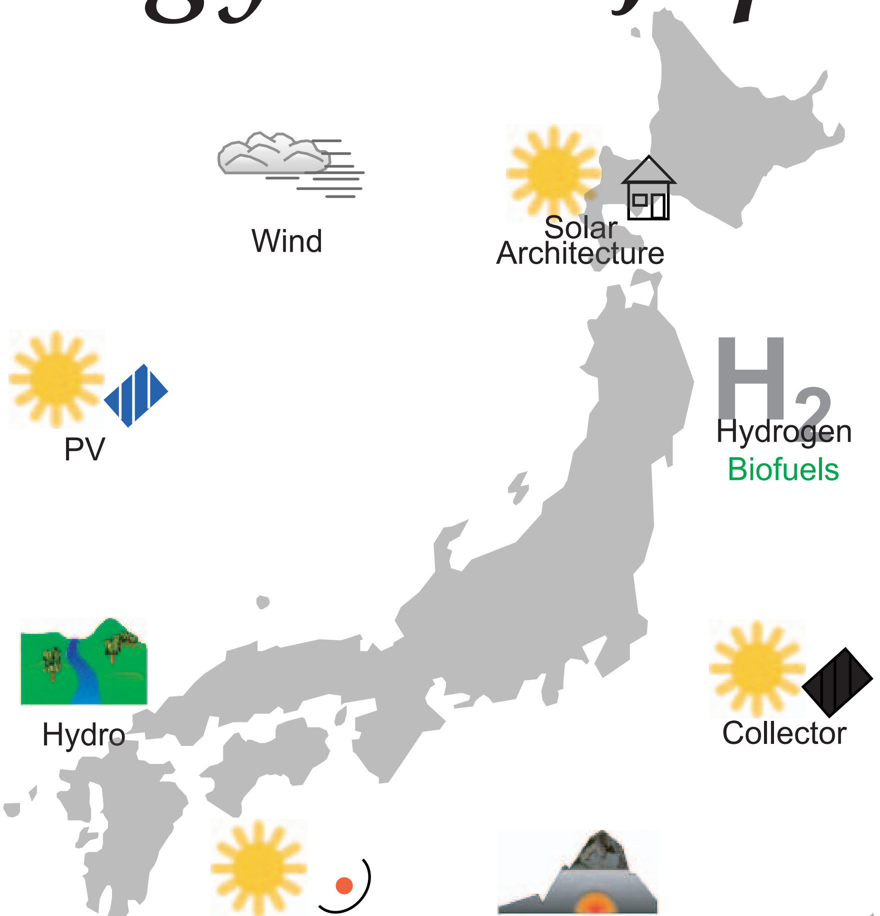
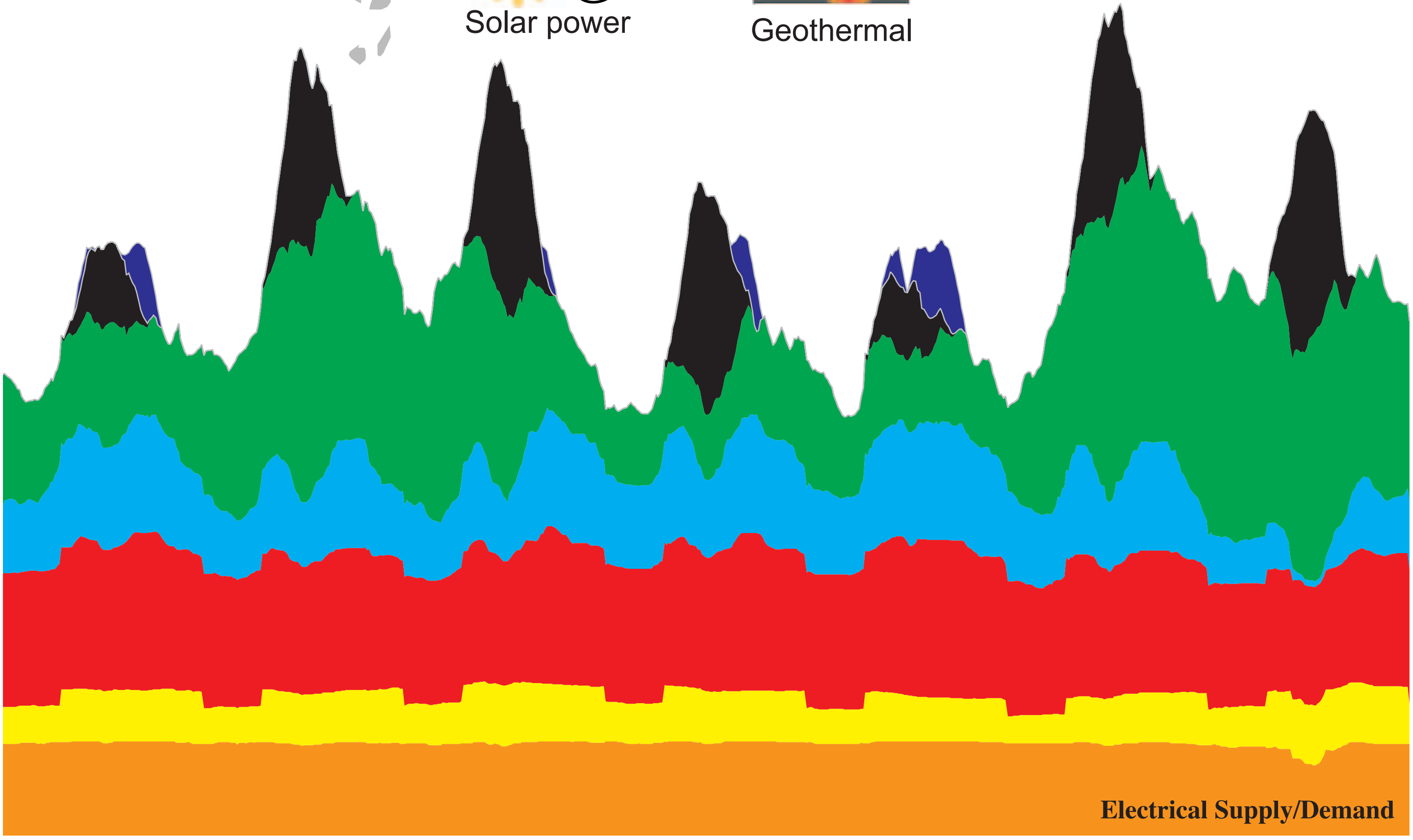
Energy Rich Japan





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Contributors:

Martin Kruska;
EUTech, Germany
Dennewartstraße 25-27, D-52068 Aachen, Germany

Daigo Ichiro, Mika Ohbayashi, Kae Takase, Iida Tetsunari;
Institute for Sustainable Energy Policies (ISEP),
Toda Bldg. 4F, 1-21, Yotsuya, Shinjuku Tokyo 160-0004, Japan

Gary Evans, Stefan Herbergs, Harry Lehmann, Karl Mallon, Stefan Peter;
Institute for Sustainable Solutions and Innovations (ISUSI),
Römerweg 2, 52070 Aachen, Germany

Dirk Aßman;
Wuppertal Institute for Climate, Environment & Energy,
Döppersberg 19, 42103 Wuppertal, Germany

Webpage: www.energyrichjapan.info

Content

2 Introduction and Foreword

„Tell people something they know already and they will thank you for it.
Tell them something new and they will hate you for it.“ George Monbiot

„Climate change is a problem with unique characteristics. It is global, long-term (up to several centuries), and involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes. This may have significant international and intergenerational implications in the context of broader societal goals, such as equity and sustainable development. Developing a response to climate change is characterised by decision-making under uncertainty and risk, including the possibility of non-linear and/or irreversible changes. This report confirms the finding that earlier actions, including a portfolio of emissions mitigation, technology development and reduction of scientific uncertainty, increase flexibility in moving towards stabilisation of atmospheric concentrations of greenhouse gases.” <1>

It was made clear in the Greenpeace report “Fossil Fuels and Climate Protection: The Carbon Logic”<2> that we need to drastically reduce our emissions of carbon dioxide to within tolerable levels, which must lead to a total phase out of the use of fossil fuels. The Carbon Logic report introduces the concept of a “carbon budget” which is the amount of oil, coal and gas that we can afford to burn if we are to avoid extensive damage to the environment caused by global warming. Just a one degree centigrade rise in temperatures over the next 100 years would cause significant damage. A temperature rise of more than one °C in that time would result in extensive damage. Greenpeace estimates that the carbon budget, which would keep any global temperature rise to within one °C, would be exceeded in about 30 years at present trends.

To stay within this budget, 75% of recoverable fossil fuel reserves must remain in the ground, never to be used as fuels. This will mean phasing out fossil fuels within this time period.

Without action to reduce emissions, 1500 billion tonnes of carbon will probably be released over the next 100 years, the majority of which will come from burning fossil fuels. This represents an enormous addition to the atmosphere of the potent greenhouse gas carbon dioxide, which began increasing significantly at the beginning of the industrial revolution. The resulting global warming would excessively raise global temperatures, increase extreme weather events, flood extensive areas of land, devastate ecosystems and accelerate extinctions. In Japan, 80% of beaches will disappear if sea levels rise by 65 cm and 90% will go with a rise of one metre<3>.

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1. Intergovernmental Panel on Climate Change (2001a).
2. Hare (1997).
3. Harasawa, H. (2001).

Rich, developed nations must take the initiative in order to make this switch because of their historical use of fossil fuels and their currently disproportionate percentage of emissions (Developed nations produce 80% of the world total greenhouse gas emissions from fossil fuels). In addition, developed countries are committed to assisting developing nations as a matter of equity and as part of their international agreements such as the Kyoto Protocol on Climate Change, aimed at reducing greenhouse gases globally.

In reality, our options for energy supply must be constrained by our impact on the environment. Fossil fuels can no longer be burned and nuclear power has proven to be dangerous and expensive and has had a disastrous impact on human health and the environment on a global scale<4>. The disaster potential posed by the nuclear industry with its associated problems of radioactive waste and the threat of terrorism or nuclear accident clearly indicate that this dangerous technology must be discontinued. The Kyoto Protocol climate conference in Bonn also agreed that nuclear power is not part of the Kyoto Protocol, having been excluded from the Joint Implementation and the Clean Development Mechanism<5>. With regard to fusion: In spite of decades of research and billions of dollars spent, nuclear fusion has not proved viable. Even if fusion will function one day it would also involve the production of radioactive waste. Renewable energies, however, offer us a sustainable solution.

2.1) Objectives of the „Energy Rich Japan“ Study

Renewable energy technologies using regional or global sources, coupled with a reduction in energy use by adopting energy efficient technologies, offer the only safe and proven option open to us for future energy needs. The objective of this study is to show that a region such as Japan is able to supply all of its own energy needs with this option, and to use the report to influence the discussion over the change from fossil and nuclear energy sources to a sustainable energy system.

The ongoing discussion regarding the potential of renewable energy and efficient design has been negatively influenced by a lack of facts about the availability and potential of these technologies. Showing that a region can provide its own energy today, purely from renewable sources will help to move us towards a fossil fuel- and nuclear energy-free system. Setting out a framework for a

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4. The 1986 explosion at the Chernobyl nuclear power station has been described as "the greatest technological catastrophe in human history". The World Health Organisation (WHO) estimated that the accident released 200 times more radioactivity than was released by the atomic bombs dropped on Hiroshima and Nagasaki. In the first year after the accident 400,000 people had to be evacuated. Large tracts of Ukraine, Belarus and Russia remain heavily contaminated to this day, and even in the UK agricultural restrictions still apply as a result of radioactive contamination from the accident.
5. The COP was held from 16th to 27th July 2001 in Bonn, Germany.

100% renewable energy supply also provides the political and societal inspiration to make moves in the direction of a sustainable future as set out at the Earth Summit in 1992.

There is rapid development within the field of renewable energy and this study presents the best available options open to society today. Naturally, society needs to work further toward improving these technologies technically and economically.

Any energy system must fit with the limitations imposed by the biosphere on a long-term scale. So what are the controls that need to be observed when planning such a system? Among other things, a sustainable energy system must not involve any loss of species. It must promote the correct use of land. It must help protect ecosystems, such as forests, as interconnected and intact living systems, protecting species diversity. It must involve no emissions of persistent, bio-accumulative or toxic wastes, no radioactive wastes and it must embody the principles of equity and equality for the present and future generations<6>.

Policies for a sustainable future promote an energy system as defined above. This means, among other things, that biomass has to be produced and used by sustainable methods. This means not degrading soils or displacing other essential uses of land such as forests, and not emitting greenhouse gases such as methane in biomass production. Biodiversity must be maintained and the energy balance of the whole biomass system must be positive. No genetically modified plants can be included in biomass production. Hydropower must not be used on a massive and destructive scale. Existing hydropower systems will be reviewed and assessed for their environmental impact. Any additional hydropower plans would promote small- and medium-scale hydro schemes on a case-specific basis. Reforestation programmes must be put in place to counter any clearances made for hydropower. Primary forest must not be sacrificed for such schemes. Photovoltaic production can involve problematic materials. Fuel cells are only emission-free when powered by clean hydrogen not acquired from fossil fuels or nuclear power.

As the saying goes, “There is no such thing as a free lunch”, but any impacts must be as minimal as possible in the total system.

This report clearly illustrates that a combination of renewable sources and energy efficient technologies can provide a solution that meets the above criteria.

The costs of such a system are lower than conventional sources when the total internal and external costs are factored, and they are becoming more price-competitive as they gain a greater per-

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6. “At the most fundamental level, the principles of equity and equality must be integrated into all aspects of sustainable development. Sustainable development is in essence a participatory process, and problems of inequality, financial insecurity, etc. will tend to hinder the participation of some sectors of the community. A major goal of sustainable development must therefore be to tackle these problems.” Source: Action Towards Local Sustainability (UK).

centage of the energy market, as production prices drop considerably with increased mass production[7]. A truly renewable energy system will only become a reality if we begin to make moves in that direction now.

2.2) General Framework

Why did we select Japan as the subject for this study? The answer lies in the challenge: if it is possible to achieve a 100% renewable energy system in Japan using today's best available technology, it would be possible to transfer and adapt the results to many other locations even to cover the whole globe.

Japan, home of and signatory to the Kyoto Protocol on climate change, has been considered energy-poor with respect to fossil fuels and has become heavily dependent on energy imports. It has consequently adopted an extensive nuclear program, which is increasingly providing more problems than solutions. Despite its history of rapid industrial change, Japan does not have great preconditions for a rapid change to renewable energy, as it is highly industrialised and densely populated with a comparatively high-energy demand. Available land and water potential is also not well placed. Japan is a relatively remote island group with few options for energy exchange with other nations. However Japan is well placed for geothermal, wind and solar energy, which are also available in most parts of world. In rising to and meeting the challenge of a 100% renewable energy system for Japan, the study proves the viability of a truly sustainable energy system, which can be transferred to other regions.

A number of factors were identified as preconditions for the report. The first was that the study should fit into the Japanese system as it is, without any major changes in lifestyles. This entailed modelling an energy demand structure without proposing any changes in living standards. No predictions for economic growth or decreases are considered either. It was also assumed that the current transport infrastructure and traffic densities would not be altered to accommodate the energy system. In other words, the goal of the project was to show that a sustainable, renewable and efficient energy system is theoretically able to supply Japan's current needs. Conservative estimates were made in all areas of the study.

The power supply of Japan is presented in the six scenarios introduced here in this study. The electrical system of this innovative energy demand and supply system is simulated with a high temporal and spatial resolution, with the SimREN computer model using real weather conditions.

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7. This is shown in Detail for Germany in the final Report of the Enquete Commission of the German Parliament „Sustainable Energy Supply against the Background of Globalization and Liberalisation“ (Source: Enquete Commission (2002)).

This is done to firstly optimise that system, and also to increase the plausibility of the energy scenarios described in this study. Three main scenarios are presented, ranging from a 50% domestic supply of energy from renewable sources to 75% and a 100% domestic supply, with variations on these three scenarios incorporating a predicted decline in the Japanese population from 127 million in 1999 to 100 million by the year 2050.

The systems described here provide a framework for a debate about the restructuring of the Japanese energy economy. However restructuring with renewable energy does not need to be limited to the ideas described in this report. Other systems that can supply Japan with renewable energy are also possible.

This study does not attempt to answer two key questions: How quickly can such a system be implemented and how much will this system cost? Both questions are often examined in energy scenarios. The majority of the project team were in agreement that answering these questions would go well beyond the scope of this study, which is meant to be a first step towards quantifying the resource. Giving answers to these questions would require an additional study.

To demonstrate the possibility of a solar energy supply for Japan, it is not necessary to specify the costs and the timeframe such a development will require. The energy system described in the ERJ Report entails a long process of developing and restructuring the present-day system according to future needs. The technological feasibility of the presented system can be proven based on present-day knowledge, applying the simulation system usedfor the first time in this study . Furthermore the uncertainty of future cost estimations and of introductory scenario studies would distract the discussion from the results of the study<8>. Namely that Japan is an energy rich country and that it can supply itself fully based on renewable sources.

However to give a sense of the order of magnitude for the time frame, existing scenarios and historical information from other regions would suggest that within 20 years at least a 30% increase in efficiency and at least a 30% provision by renewables is possible, but this is highly dependent on the availability of resources, the starting point and the political measures in the country in question.

From the basic desire to illustrate the feasibility of a ‘100% sustainable region’, Greenpeace International and Greenpeace Japan commissioned a scientific collaboration with institutions in Europe and Japan. The contributors included EUTech (Germany), ISEP (Japan), Wuppertal Institute (Germany) and ISUSI (Germany) with an international team. Close co-operation between the groups was ensured at all times.

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8. More about this in: “Energy Rich Japan - Aspects of Costs and Timeframes“.
available under www.energyrichjapan.info

The main emphasis of the work of EUTech lay on the analysis of efficient energy technologies especially in the industrial sector. ISEP concentrated on supplying data on Japan (e.g. the potential of renewable energies, data on electricity demand and weather data) and on formulating political goals and accompanying the development of the supply and demand models critically. The Wuppertal Institute's main emphasis lay on formulating the demand model. The international team of ISUSI provided the supply model, developed a Japanese version of the computer program SimREN, realised the simulation and co-ordinated the scientific work.

All meetings where done in Japan and the team worked together on all parts of the study. Such a study cannot always be realised without differences of opinion. Insofar as they could not be clarified in discussion, I accept the responsibility.

Prominent scientists from Japan and from Europe were consulted as independent external reviewers during the preparation of this report: Dr. Robert Gross (Imperial College UK), Dr. Jorgen Stig Norgard (Technical University of Denmark), Dr. Yasuhiro Murota (Shonan Econometrics), Dr. Hidetoshi Nakagami (Jukankyo Research Institute), Dr. Naoto Sagawa (Jukankyo Research Institute), Dr. Hermann Scheer (Eurosolar and alternative Nobelprize winner) and Dr. Jörg Schindler (L-B Systemtechnik).

I wish to thank them for their work, their criticism, contributions and support towards publishing this study. We have included the in some points contradictory suggestions in the study as far as possible. I would like to thank Jörg Schindler for his contribution to the hydrogen part of the report. Many thanks to Hermann Scheer for the support the “World Council for renewable Energies” (WCRE) gave the report during publication.

Lastly I wish to thank Greenpeace International, Greenpeace Japan and especially Lynn Goldsworthy for the support with this study, without which this report would never have been realised.

How to achieve to a sustainable energy system is the question I hope we have addressed with this study. What we need now is the desire and will to make it happen.

Harry Lehmann

Scientific Coordinator of the
Energy Rich Japan Research Team/Study

Head of Institute for Sustainable Solutions
and Innovations

3 Methodology

The reason for undertaking this study was to examine and then show how Japan can supply itself exclusively with technologies that utilise renewable energy sources. The study looked at the full range of renewable energy sources available, including supply solely from regional (Japanese) sources. In addition, it was important to formulate and test a plausible model for an energy demand based on efficient technologies.

An energy system consists of inputs (such as oil, coal and gas, nuclear power, hydropower, photovoltaic, wind power etc) and outputs (such as energy in the form of electricity, heat and fuels), which vary over time. Energy demand is that part of the system, which consumes energy in the form of electricity, heat and fuels provided by the supply side of the system to make available services such as heating, lighting, transportation, communication and power for appliances.

In order to develop a sustainable system, demand and supply must be researched. In order to accurately analyse energy consumption, a demand model was built to reflect the actual demand in Japan in detail by identifying all areas and sectors where energy was consumed. These sectors included industry, commercial, residential and transport. It was then possible to detect all potential reductions in each sector.

In order for the study to remain conservative, it was considered an important precondition that the project team researched the possibilities of reducing demand without making any changes to the level of industrial production and without involving any reductions in the standard of living or making lifestyle alterations. This established that a reduction in demand is theoretically possible using today’s best available technologies (BAT) and can be implemented without having to stipulate a restructuring of society or industry. For the same reason, other factors that would have helped to reduce demand, such as increases in resource productivity or moves toward sufficiency were also not included.

The population decline scenarios consider a reduction of approximately 27 million. This demographic trend, predicted by the Japanese<9> themselves will see a generally more elderly population totalling 100 million by the year 2050. In order to address this in the “Energy-Rich Japan” scenarios, a straightforward decline was adopted for the subsequent demand reduction. In reality a declining and more elderly population would have a far more complex effect on demand. Smaller households generally use more energy per capita and a smaller workforce would impact on production levels<10>. Energy use per capita would decline in some areas and increase in certain oth-

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9. National Institute of Population and Social Security Research (2001).
10. Increasing energy use over time, i.e. future trends to smaller households, while an increasing issue in Japan, is not addressed in this report.

ers. There is no clear existing connection that can be drawn upon in order to make a prediction, so for the sake of simplicity a linear decline was adopted.

Japanese energy demand data was taken from the year 1999, which was chosen as a reference year for the determination of the Energy-Rich Japan (ERJ) Demand Model. Research was conducted using both “bottom-up” and “top-down” approaches. In the bottom-up approach, research into energy saving measures was applied, such as identifying and implementing the latest best available technologies and environmental designs in all sectors of demand, such as efficient vehicles, and then calculating the decrease in demand. With the top-down approach, European studies conducted in the area of energy efficiency and environmental designs were adopted in all sectors in Japan. The advanced level of technology in Japan meant that European efficiency potentials had to be lowered by varying percentages according to the sector. This was supported by comparing the production of specific goods, such as steel production statistics in Europe and Japan. For example, the energy required to produce a tonne of steel in Japan was compared to the energy required for producing a ton of steel in Europe. Taken across all areas of industry, commercial, residential and transport, this provided a clear indication of the comparative efficiency potentials and therefore the difference in potentials required for the study. These potentials were then applied to the ERJ Model.

It must be noted that increases in efficiency must not be considered as “income” (in energy terms) and then lead to increased consumption or output i.e. energy “saved” by efficiency must not then be considered available for “spending” elsewhere. This is commonly referred to as the “rebound effect” and must be avoided if energy consumption is to be reduced.

The renewable sources in the supply model required to meet this reduced demand were then determined. To this end, a supply model was developed to cover electricity, heat and fuels. The ERJ Supply Model incorporated a wide variety of the latest renewable energy technologies such as electricity from photovoltaic cells, wind and hydropower, heat from thermal solar panels and geothermal sources, hydrogen for fuels and energy storage from diverse renewable sources. The cogeneration of heat and power was also utilised.

At the time of preparing the study there are significant uncertainties regarding the potential volume of sustainable produced domestic biomass in Japan. For this reason, details regarding the value of biomass in Japan were not incorporated in this study. Nevertheless, biomass will make an important contribution to a future energy supply.

The ERJ Supply Model was designed to supply energy in the form of electricity, heat and fuels at anytime throughout the year. To achieve this, fluctuating sources, such as wind and solar power were combined with adjustable suppliers such as geothermal or combined heat and power, to provide a reliable supply of energy throughout the year. Surpluses in the electrical supply system were converted into hydrogen that was used as a fuel for different types of factories or processes.

Energy is supplied in the form of electricity, heat or fuels. Heat and fuels have the advantage that they can be stored for later use and can be easily transported. So it is not necessary to consume heat and fuels immediately or in the place they were produced. Heat can be stored in thermal reservoirs and distributed via district heating networks. Both heat and fuels dissipate with time, which sets a limit to storage time and distribution distance. As for fuels from biomass or hydrogen, there is no limitation in storage time or in transport (depending on the fuel type - solid, liquid or gaseous) but storage losses must be considered.

The situation is completely different with electricity. The necessity of producing enough electricity, on demand and on time, makes this type of energy the most critical component in an energy supply system. While electrical transport via the public grid is quite unproblematic, storing electricity directly on a large scale is material- and cost- intensive. Indirect storage is used in the study by utilising hydrogen and pumped storage.

An energy supply system which is based solely on renewable sources increases the focus on timely energy provision due to the fluctuating nature of some renewable energy sources, such as solar and wind. Including such fluctuating sources into the public electricity supply means that the proportion of electricity produced by those sources might decrease suddenly. Of course electricity production from fluctuating sources can be estimated by weather forecasting but a portion of uncertainty still remains (particularly in a world starting to show the effects of climate change). Fortunately, there are other renewable technologies with the ability to deliver energy on demand; hydropower and geothermal power plants give direct access to renewable sources, cogeneration and other energy sources can use fuel from renewable sources (e.g. hydrogen or biomass).

The challenge in designing a reliable fully renewable energy system was to find a combination of technologies where the pros of some types balanced out the cons of the others. A reserve capacity is necessary as a backup for fluctuating sources, especially in the electrical system. The size of the reserve capacity required can be minimised by designing a combination of renewable technologies where fluctuations in production match a varying demand, so that any fluctuations in supply never lead to electrical production that cannot meet the demand.

The focus in designing the ERJ Supply Models was therefore on the electrical subsystem, as this is the most (time) critical component of supply. The simulation of the electrical energy supply using SimREN, a specially designed software program, was used to optimise the system by first determining the amount and locations of energy sources and performing a simulation run.

For the study Japan was divided into twelve geographical regions<11>, which were able to exchange energy supply with each other. Weather information from 153 weather sub-regions across Japan, including wind speeds and temperatures ensured that Japanese weather was realistically reflected in the simulation. In addition, 66 of these weather stations provided solar radiation data. River level data from 1999 was also available for the estimation of the existing hydropower capacity. This enabled a realistic reflection of the energy potential of fluctuating energy sources such as windmills. A resolution of fifteen minutes also made sure that changes in weather conditions and hence supply were incorporated in the simulation, guaranteeing a reliable energy supply throughout the year. Intelligent control of differing renewable energy sources was performed using an energy manager.

Improvements were implemented in the supply model in order to optimise the system, such as increasing the number of windmills in one region, or altering the mix of renewables, so that the goal of using regional Japanese sources to supply electricity domestic without any loss of integrity in the system was achieved. The heat and fuels supplying system was then designed.

The result was Scenario One, which is described in detail in this report. This system is capable of reliably delivering electricity, heat and fuels in the demand and supply. Then a number of variations on this scenario were calculated to show different energy mixes including a version which supplies Japan completely with energy from domestic sources. A variation on these three scenarios was calculated incorporating a predicted decline in the Japanese population from 127 million in 1999 to 100 million by the year 2050.

Three prominent scientists from Japan and four from Europe were consulted as external reviewers of the draft of the report. Their comments were taken into account as much as possible in order to produce this final version.

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11. The remote islands of Okinawa were not considered as a region, but were partially included into Kyushu South.

4 Demand Model

A comprehensive energy demand model was required in order to gain a realistic picture of Japan's energy system. An energy system consists of inputs and outputs, which vary over time. Energy demand is that part of the system which consumes energy in the form of electricity, heat and fuels provided by the supply side of the system, to make available services such as heating, lighting, transportation, communication and power for appliances.

In order to accurately analyse energy consumption, a demand model was built which reflected the actual demand in Japan in detail by identifying all areas where energy was consumed. It was then possible to detect all potential reductions. This was achieved by various means, such as intelligent design or replacement with efficient technologies.

Best available technologies (BAT)<12> were implemented in the industrial, residential and commercial demand sectors, where straightforward replacement would result in the reductions reported in this chapter. The transport sector was more problematic with regard to availability of the technology, although energy efficient vehicles (which consume less than 2.5 litres per 100 km) are now available on the market and the first fuel cell vehicles using hydrogen are now in the production stage, the necessary infrastructure for supplying hydrogen is not yet in place.

The renewable technologies required to meet the reduced demand were then determined in the supply model. A detailed explanation of supply and hydrogen can be found in the supply model section.

To analyse the potential reductions, the project team considered the total energy demand in sectors<13>:

- Industry
- Residential
- Commercial
- Transport

Each sector was investigated in terms of its current energy demand in its various energy forms.

Japanese energy demand data was taken from 1999, which was chosen as a reference year for the determination of the Energy-Rich Japan (ERJ) Demand Model. Research was conducted using

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12. The term "best available technology" (BAT) is taken to mean the latest stage of development (state of the art) of processes, of facilities or of methods of operation, which indicate the practical suitability of a particular measure for producing electricity, heat or fuels and/or improving efficiency.
13. EDMC (2001).

both “bottom-up” and “top-down” approaches. By identifying and implementing the latest best technologies and environmental designs in all sectors of demand, and research into energy saving measures was applied in the bottom-up approach, such as using efficient vehicles and then calculating the decrease in demand. With the top-down approach, European studies conducted in energy efficiency and environmental designs were adopted in all sectors in Japan. Because of the advanced level of technology in Japan, European efficiency potentials had to be lowered by varying percentages according to the sector. This was supported by comparing the production of specific goods, such as steel production statistics in Europe and Japan. For example, the energy required to produce a ton of steel in Japan was compared to the energy required for producing a ton of steel in Europe.

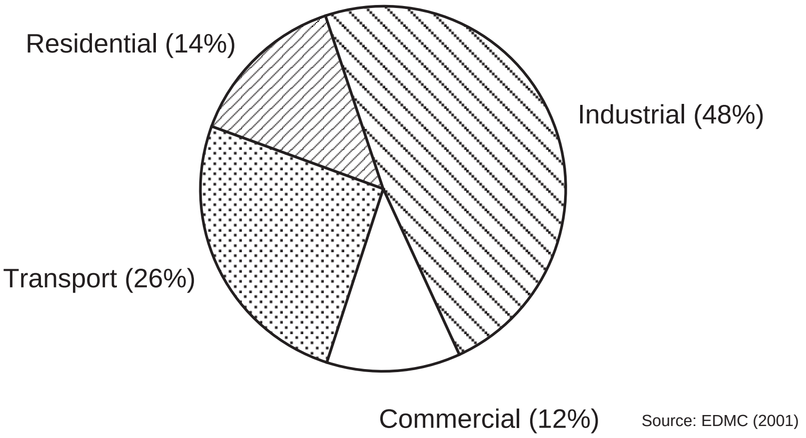

Figure 1 : Final energy demand per sector in Japan in 1999. Source: EDMC.

Lighting – A Cross-sector Technology

Lighting is considered in all sectors of demand, but deserves special mention here because of its cross-sector nature. Other areas of demand such as water heating are also cross-sectoral in nature, but are described in detail in the respective sectors of demand.

A number of measures can dramatically reduce the energy required for lighting in all sectors.

Among the largest reductions result from using highly-efficient lamps, efficient fluorescents and fixtures, occupancy detectors (up to 60% savings in one study<14> , electronic ballasts, daylighting (also daylighting using ‘light pipes’) and LEDs (for example in exit signs). Solar architecture and intelligent building design (reorganisation/retrofitting of existing buildings and the adapted planning of future buildings) reduces the general need for artificial lighting<15>.

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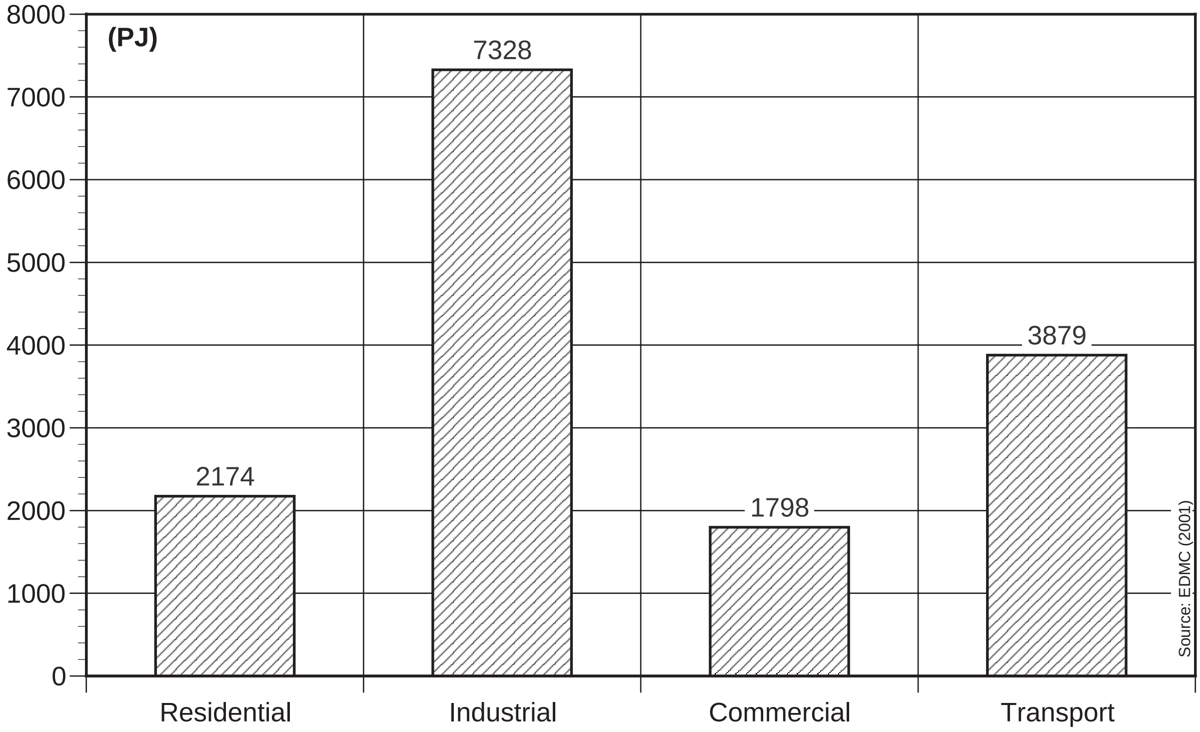
14. NEMA (2001).
15. ICCEPT (2002).

According to the IPCC[16], integrated building design projects have shown total energy savings of between 30% and 60% in the residential sector, and 13% to 71% in the commercial sector. The ERJ demand reduction estimates of 54% for both the residential and commercial sectors in Japan fits within these ranges.



Source: EDMC (2001)

Figure 2 : Final energy demand in Japan per sector in 1999

4.1) Industry

Japanese industry, which in 1999 consumed 48% of the total final energy demand, revealed energy savings of nearly 40% in the ERJ Demand Model.

The Figure 3 : "Changes in energy intensity of major industries in Japan 1973 – 1998" shows improvements in industrial energy efficiency since 1973. Note that efficiency has actually seen a general decline since 1990.

The sector was broken down into the following sub-sectors: agriculture, forestry and fisheries, mining, construction, food and tobacco, fibres, paper, pulp and print, chemical industries, ceramics and cements, iron and steel, non-ferrous metals, metal and machinery, and other industries.

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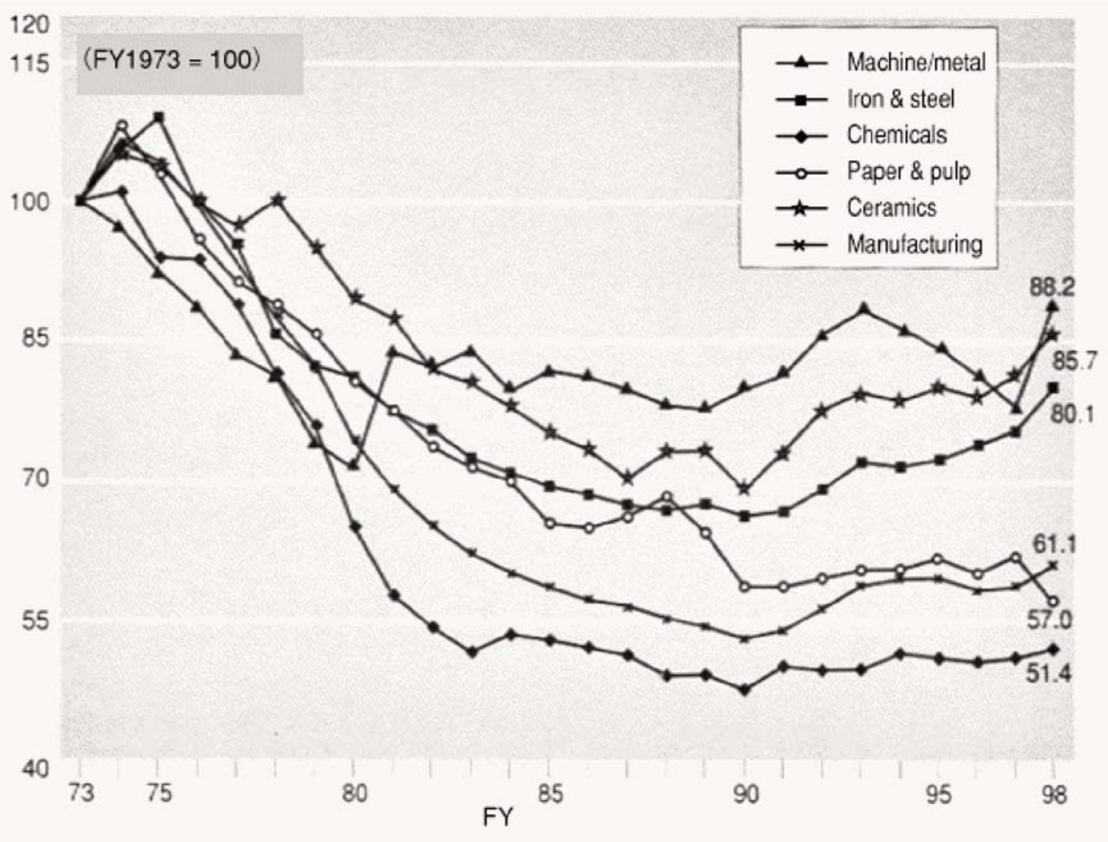
16. IPCC (2001b).

The chosen approach was taken, based on bottom-up data from The Netherlands, Germany and Scandinavia. The technologies used in both regions are very similar (e.g. for steel production, chemical products etc). European industries are efficient but in certain branches their efficiency is less than in Japan. As Japanese industry is one of the most efficient in the world, the potential increases in efficiency found in Europe were reduced in certain cases to reflect this. This difference in potential was estimated by comparing existing Japanese-European studies for particular branches (e.g. iron and steel, chemical and cement). Many possibilities for reducing energy demand in industry were discovered using this method.



Source: Energy Conservation Centre of Japan<17>

Figure 3 : Changes in energy intensity of major industries in Japan 1973 – 1998

Because of the diverse character of the industrial sector, possible energy efficiency improvements were estimated sub-sector by sub-sector. Branch specific investigation would definitely have been better, but would be extremely time and cost intensive. However, some overview studies exist (AEA (2000), Bach (1993), de Beer (1994), ISI (2001) etc.), which are based upon approximately one thousand detailed investigations in total (made within the last 15 years).

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17. Prepared based on EDMC (2000).

As with most industrialised countries, the chemical, then the iron and steel industries are the most energy intensive, followed by the ceramics and cement industries. In the chemical industry, savings of 35% came from measures such as adopting membrane processes, electronic control systems, fuel switching, heat recovery, better efficiency, hydrogen recovery, better integration of hot and cold streams, entirely new processes (such as the ICI AMV process for the synthesis of ammonia), overall good housekeeping and energy management<18>. In the ceramics and cement sector, changing the process from wet to precalciner kiln conversion saves 46% of the total energy in cement production (a saving of 1.1 GigaJoule per ton during production).

Improvements in furnace design and efficiency alone offer a large saving potential by using heat recovery with gas-fired burners for industrial furnaces. This technology makes furnaces more efficient by recovering waste heat from exhaust flue gases to preheat combustion air. According to one study, the conservation potential for the industrial sector from using such furnaces represents ten percent of the total industrial energy consumption. Simply by using the most efficient pumps and piping systems, a 70% reduction in energy use for pumping can be achieved, resulting in a potential three percent reduction in the industrial electricity demand. Other examples are using steamless brewery (using hot water at four different temperatures; using pinch-point methodology) leads to a 60% reduction of energy demand in this process. Heat recovery, burner optimisation, membrane techniques, energy management and good housekeeping are only a few examples of energy demand reduction options<19>. Good housekeeping and energy management is estimated to reduce the overall final energy consumption by at least five percent in all sectors of industry<20>.

The technical potentials in this report express the maximum potential possible using all technical options, whereas economic potential describes the energy reductions that can be afforded within a certain timeframe. For example, the technical reduction potential in the mining industry lies between 50% and 70% for fuels<21> (depending on the fuel type), whereas the economic reduction potential between 1990 and 2015 was estimated at between 43% to 59%<22>.

4.1.1) Agriculture, Forestry and Fisheries

Investigating the efficiency potentials for this sector was quite difficult because no detailed data of the sector was available. Therefore, only a rough estimation can be made. In the agriculture branch, fuels are mainly used for mobile farming equipment (tractor, trucks etc.), greenhouses and

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18. Worrell, E. et al. (1999).
19. AEA (2000), Bach, W. (1993), de Beer, J. et al. (1994), de Beer, J. (1998), Prognos/EWI (1999).
20. de Beer, J. et al.(1994).
21. Polenz, C. (2002).
22. de Beer, J. et al. (1994).

space heating. Electricity is mainly used for lighting and different operations in farmers' buildings. In forestry, fuels are also used for mobile equipment but the share for greenhouses and space heating is smaller as well as the use of electricity. In the fishery industry, mainly fuels are used for boats, cooling, the whole equipment etc. Electricity is always generated directly onboard.

Therefore, the experiences of corresponding branches and technology areas (transportation, cooling, lighting, electric motors and drives etc.) have been used for estimating the reduction potentials. In Europe a 60% reduction is seen as possible.

A reduction potential of 52% was calculated in this sector for Japan.

4.1.2) The Mining Industry

The German forecast from EWI/Prognos (1999) shows a reduction of about 70 % for fuels and 32 % for electricity by 2020. The reason is a mixture of technological progress and structural change, where the main aspects are improved performance, better equipment, fuel switching (favouring natural gas), increasing trade and decreasing production. One should be aware that this is not a potential estimation but a forecast; potentials must be even higher.

Polenz, C. (2002) tried to estimate the technical potential in the mining industry. Due to his analysis, this lies between 50% and 70% (this varies with the fuel type) and for electricity by about 40%. On the other hand, de Beer, J. et al. (1994) analysed the economic reduction options between 1990 and 2015, which are shown as 43% to 59% for fuels and 35% for electricity. They were not able to include all possible measures, so potentials must also be higher than presented.

Following Bach, W. (1993), fuel consumption can be decreased by over 30% and electricity by nearly 40% by 2020 by using better equipment and more efficient transportation systems. The diffusion is assumed at a medium rate, therefore technical potentials are higher.<23>

A reduction potential of 39% was calculated in this sector for Japan.

4.1.3) Construction Industry

The construction industry in general is a sector where not much attention has yet been given to energy saving. Energy consumption can be divided into fuel for mobile equipment and asphalt-mixing installations and electricity for various appliances.

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23. Advances in technologies since the publication of the Bach study would show increased potentials.

Polenz, C. (2002) estimated a technical potential of about 65% taking more measures into account (more efficient mobile equipment and trucks, burner optimising, improved insulation, heat recovery etc.), but the potential shown does not fit exactly to this branch. de Beer, J. et al. (1994) shows an economic reduction potential of about 27% by 2015 due to burner optimising, heat recovery, drum mixing installation, better mobile equipment etc. EWI/Prognos (1999) assume a reduction of about 18% by 2020 compared to 1995, mainly due to improved motor drives and electronic regulation. In all studies, the electricity reduction potential is about 35%.

A reduction potential of 24% was calculated in this sector for Japan.

4.1.4) Food and Tobacco

The food and tobacco industry consumes heat at different temperature levels, but the processes are very often not optimised so that there is still a great energy saving potential.

de Beer, J. et al. (1994) revealed a techno-economic reduction potential of about 61% (ranging for the various branches inside the sector from 35% to 81%). Polenz, C. (2002) even speaks of a saving potential between 66% and 72%.

According to Bach, W. (1993), the demand reduction between 1990 and 2020 could reach 54% in total (sugar industry 64%, semi luxury industry 67%, and others 43%). The main measures would be heat-recovery systems, modern evaporation, continuous processes, combined use of compressors and gas turbines and the use of membrane techniques. In the German business-as-usual study by EWI/Prognos (1999) a reduction of 25% is forecast, but a lot of efficiency potentials are not yet included. AEA Technology plc investigated a 33% cost-effective saving potential, but they again only included a few measures due to time limitations.

On the electricity side, the range of the economic reduction potential is from 25% to 35% (again only for some measures) and for technical potentials of 49% (due to speed control, improved pumps and appliances etc.).

A reduction potential of 41% was calculated in this sector for Japan.

4.1.5) Fibres

Overall 80% to 95% of the fuel demand in this industry is consumed for process heating, about one third of this heat is used only for drying. The remaining percentage represents space heating. Heat recovery, retrofitting of the dryers, airless drying, gas heat pumps, improved insulation, good housekeeping and management, infra red pre-drying, dielectric drying in vacuum etc. can lead to significant reductions.

The most detailed analysis, which included all possible measures that are discussed, investigated a fuel saving potential of up to 73% <24>, while other studies show lower values. Polenz, C. (2002) revealed potentials between 50% and 57%, these were calculated at the beginning of the 1990s, when some new technologies were not known (e.g. Bach, W. 1993 showed 54 %).

The more mid-term oriented studies of EWI/Prognos (1999) and AEA (2000) estimated a cost-effective reduction of about 30 % (forecast by 2020) and 37% (potential by 2015) respectively. In both cases, only some measures were taken into account.

Saving options for electricity are not as good as for fuel, but they are still high (technical conservation potential between 30% and 45% are due to different analyses). Possible measures are efficient motors, lighting, adjustable speed drives, heat recovery, retrofitting, airless drying, gas heat pumps, improved air conditioning etc. Even in the business as usual forecast by EWI/Prognos (1999) the reduction would be 30%. AEA (2000) also showed some cost-effective measures that would lead to a reduction of 37% by 2015.

A reduction potential of 50% was calculated in this sector for Japan.

4.1.6) Paper and Pulp

The entire sector can be divided into paper mills, paper converting industries and corrugated board manufacturers. In the period from the seventies until 1990, the specific primary energy requirement dropped in the mill industry due to savings in the final heat demand and the application of cogeneration. The production of pulp out of wood is an energy intensive process; depending on the pulping process the net primary energy consumption varies from 11 GigaJoule per ton to 13 GigaJoule per ton of pulp.

Although the production lines have been well known for a long period, there are still a lot of saving options. Consumption could be economically reduced by 22% by using continuous cooking processes and efficient pumps, making various process modifications and optimisations and introducing recycling systems <25> or 28% <26>.

Detailed analyses even investigated techno-economic options of about 67% energy demand reduction (69% for paper mills) <27> as well as a technical potential of about 83% (but compared

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24. de Beer, J. et al. (1994).
25. Martin, N. et al. (2000).
26. EWI/Prognos (1999).
27. de Beer, J. et al. (1994).

with 1990) [28] . Therefore, industry also has to implement energy management systems, completely covered drying sections, better insulation of the hood condensation etc.

Technical electricity demand can be diminished by up to 75% [29] due to measures such as efficient and direct drive motors, more efficient pumps, energy management, improved lighting, adjustable speed drives, efficient machines on all levels, new pressing techniques (e.g. extended nip press) etc. The economic potentials are revealed as 20% [30] (only a few measures) to 48% [31] (the entire range of options).

A reduction potential of 49% was calculated in this sector for Japan.

4.1.7) Chemical Industries

The chemical sector is the major energy consumer in Japanese industry. The sector is very diverse; it can be divided into various sub-sectors like fertiliser-production, the petrochemicals, inorganic chemical, synthetic resins, pharmaceutical and others. Therefore, it is hard to analyse the possible saving potential for this sector, but nevertheless, some good estimates exist.

Bach, W. (1993) investigated a technical reduction potential of about 57%, Polenz, C. (2002) even 60% to 70%. According to de Beer, J. et al. (1994), 32% of the demand could be reduced economically, but not all possible measures have been included. AEA (2000) on the other hand showed a cost-effective saving potential of 37% by 2015. That corresponds with some very specific analyses made by Worrell (1994) for fertiliser (44 % reduction options), plastics (ten %) and others. Very interesting in this case is the business as usual study by EWI/Prognos (1999); the authors foresee a reduction in the German chemical industry (which is already quite efficient) of 53%.

However, all of these investigations belong to measures like membrane processes, electronic control systems, fuel switching, heat recovery, better efficiency, hydrogen recovery, better integration of hot and cold streams, entire new processes (like the ICI AMV process for the synthesis of ammonia) and overall good housekeeping and energy management.

The electricity saving potential is similar to the fuel case. Due to electronic control systems, well-dimensioned motors, adjustable speed drives, improving pressurised air systems, efficient lighting etc. energy requirements can be reduced by up to 55% [32] or even 70% [33]. Concerning de Beer

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[28] Bach, W. (1993).
[29] Bach, W. (1993).
[30] AEA (2000).
[31] de Beer, J. et al. (1994).
[32] Bach, W. (1993).
[33] Polenz, C. (2002).

et al. (1994) 45% of the demand can be economically reduced (range from 26% to 50% for the various sub-sectors, not all possible measures are included). Without changing politics, the German electricity demand in the chemical industry will be reduced by 33% by 2020 <34> .

A reduction potential of 35% was calculated in this sector for Japan.

4.1.8) Ceramics and Cement

The manufacture of building materials and earthenware is the third largest sub-sector in Japanese industry from the point of view of energy consumption, although in the total size it is not comparable with the previously mentioned chemical industry. The ceramics industry in Japan actually saw a decrease in efficiency of over 15% between 1990 and 1998.

The energy demand in this sector would be reduced about 30% in the case of cement and up to 70% in the case of ceramics <35> by using improved recycling, furnace optimisation, heat recovery, insulating kiln wagons, improved process control, fast firing roller kilns, heat pumps for drying, fluidised bed reactors, good housekeeping etc. de Beer, J. et al. (1994) estimated economic reduction options from 43% for glass to 59% for pottery; cement is shown with 46%. Polenz (2002) produced results in the same range. Martin, N. et al. (1999) made a detailed analysis only for cement. According to him, the technical potential is 40% to 45%, the economic potential between 11% and 18%. Energetics (1997) made such an analysis for glass production and they show a technical reduction potential of about 40% to 50%.

Electricity reduction options are not so great, but there are still good opportunities, as in most of the other sectors. Bach, W. (1993) estimated a potential between 40% and 50% (depending on the branch); according to Martin, N. et al. (1999) and Energetics (1997) the potential for both cement and glass are quite similar to the fuel case mentioned above. The economic potential is given about 35% by de Beer, J. et al. (1994). In Germany, energy consumption in this sector will be reduced about 18% by 2020 in the conservative BAU case <36>. Measures include mill and sinter optimisation, new processing, furnace optimisation, heat recovery, efficient machines, fans and lighting etc. With furnace optimisation alone, heat recovery and a few other measures, energy demand can be reduced economically by 24% by 2020 under business as usual conditions <37> (1995 to 2020).

A reduction potential of 41% was calculated in this sector for Japan.

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34. EWI/Prognos (1999.)
35. Bach, W. (1993).
36. EWI/Prognos (1999).
37. EWI/Prognos (1999).

4.1.9) Non-ferrous Metals

Energy consumption in this sector is dominated by the production of aluminium, which is very energy intensive. Therefore, most of the analysis potential is focused on this metal. However, the non-ferrous metal sector in Japan is not very important compared with the other industrial sectors.

On the fuel side, the reduction options are quite small. According to Bach, it should be possible to reduce consumption by 27% by using new processes etc. but Bach, W. (1993) made analyses relating to technical options. According to de Beer, J. et al. (1994) demand could be reduced by about 15% by utilising techno-economic reduction options (modern furnaces, new processes etc.). AEA (2000) on the other hand shows a cost-effective saving potential of about 21%. The most important reduction for fuels and electricity can be reached by changing the production structure, which means less primary production and more secondary production by the recycling of aluminium. On the basis of such an assumption, EWI/Prognos (1999) assumes a reduction in Germany of about 48% by 2020 through process improvements and reduced primary production.

In the case of electricity, the situation is different because efficiency potentials are much higher. Relating the use of new electrodes and processes, higher recycling rates, further development of the Hall-Heroult process and of furnaces, modern furnace technology, insulation, and good housekeeping, a reduction of about 69% is feasible <38>. AEA (2000) and de Beer, J. et al. (1994) both estimated the economic electricity reduction potential at 21%. Assuming significant improvements in the process technology as well as a change from primary to secondary production, EWI/Prognos (1999) forecast a reduction of about 59% by 2020.

An overall reduction potential of 31% was calculated in this sector for Japan.

4.1.10) Metal and Machinery

This sector again consists of different sub-sectors such as metal manufacturing, mechanical industries, electro-technical industries, transport equipment, foundries or engineering industries. These sectors are not so energy intensive as energy costs are only a small amount of the total production costs, and therefore the potential for energy conservation is lower. This minimum potential is also a consequence of a lack of knowledge concerning energy conservation in these companies (apart from foundries). More intensive research would reveal greater potential in this sector.

Fuels are mainly used for process heat and for space heating. Space heating can be improved by using insulation etc., but also the production and use of process heat can be further developed. Furnaces are often in a bad condition; waste heat can be recuperated.

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38. Bach, W. (1993).

According to Polenz, C. (2002) technical potentials reach 85%. According to Bach, W. (1993) the technical potentials are less, but quite high with 41% (ranging from 23% to 54 %. It has to be taken into account that at the beginning of the nineties, knowledge about reduction options concerning space heating was not as good as today). EWI/Prognos (1999) foresees a reduction of about 36%. de Beer, J. et al. (1994) revealed an economic reduction potential of about 77%.

Electricity demand can be reduced by 42% <39> due to improved motor drives, electronic regulation, better appliances, speed control systems, and best available technologies for lighting etc. But potentials even seem to be higher because EWI/Prognos (1999) assumed a reduction of about 41% by 2020 in the business as usual case. The economic potential lies between 12% <40> and 20% <41>.

A reduction potential of 43% was calculated in this sector for Japan.

4.1.11) Iron and Steel

The iron and steel industry saw a 20% increase in efficiency between 1973 and the 1990s <42>, although a general reduction in efficiency has been seen in Japan between 1990 and 1998 (with a reference year of 1973=100), the peak efficiency was seen in 1990 at 66.2% of the 1973 level. Efficiencies have declined in most industrial sectors since then, especially in iron and steel and ceramics. (See Figure 3, "Changes in energy intensity of major industries in Japan 1973 – 1998")<43>.

Nevertheless, there are still large energy efficiency improvement potentials. Table A below lists the ranges of efficiency improvements reported from various sources. The wide variation (six percent to 60%) is due to differences in the basic assumptions used, plus the wide variation in the time period studied. The most recent study made of the technical potential was conducted for the IPCC (2001a), and described a current technical reduction potential of 10% to12% in Japan using today’s best available technologies. The same source however, also shows a potential increase in efficiency of about 30% if an energy efficiency index is used. The index is structured to show that if all processes operated at a best practice level, the index would be 100. Japanese iron and steel in 1991 showed a normalised efficiency of approximately 135, that is approximately 30% less efficient than its theoretical potential (with a statistical uncertainty quoted by the IPCC of 5%). Further to this, the efficiency of this sector peaked in the early 1990s and has continued to decline

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39. Bach, W. (1993).
40. de Beer, J. et al. (1994).
41. Polenz, C. (2002).
42. IPCC (1995), ECCJ (1999).
43. EDMC (2001).

since (see Figure 3, "Changes in energy intensity of major industries in Japan 1973 – 1998") meaning that the reduction potential has actually increased since the IPCC reference year of 1991. The Wuppertal Institute in Germany estimated a reduction potential of 38% for the ERJ Study, which compares favourably with the IPCC figures.

A number of studies have reported reduction potentials above these figures. Bach, W. (1993) quotes a 48% reduction due to increased share of electric arc furnace (EAF), compared to the more energy-intensive basic oxygen furnace (BOF) and a large reduction of pig iron. EWI/Prognos (1999) quotes 55% for similar reasons, and Polenz (2002) quotes the largest reduction potential of 60%. It must be noted that reductions quoted here vary greatly due to the assumptions used. These include changing production methods involving the reduction of primary steel compared to secondary steel, process changes and other factors, which are discussed below.

Future efficiency increases have been estimated at around 1.5% to 2% per year on average for OECD countries from the year 2000 <44>. Taking this estimate, a reduction of around 30% can be considered possible before the year 2020.

Greater reductions would be possible by increasing the amount of secondary (or recycled) steel compared to primary production, as primary steel requires a large percentage of energy-intensive pig iron. The quality of secondary steel can be an issue due to contamination by impurities in the scrap, which could be addressed by considering the design of the primary steel during production <45>. This would mean a move toward closed loop recycling in the iron and steel industry. Japan is currently the second largest producer of steel in the world. In 1999, 74.52 million tons of pig iron and 94.19 million tons of crude steel were produced in Japan. In 2001, Japan imported over 126 million tons of iron ore and 63 million tons of coal, (approximately 70% from Australia) and exported six million tons of ferrous scrap<46>.

An increase in material productivity would also mean a reduction in the demand for steel in products in Japan. This will have a dramatic influence on production in Japan in the future. Moves away from industrial production toward the service sector in Japan will also reduce the demand for steel. The last fifty years has seen dramatic changes in iron and steel production quantities and efficiencies. It is safe to assume that the future structure and size of the iron and steel industry in Japan will certainly look very different in fifty years time to today.

Considering all the above factors, a technical demand reduction potential of 30% was adopted for the ERJ Study without making changes to production levels or quality. This can clearly be considered as a conservative estimate, because tough policies for improving efficiencies and reducing

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44. IPCC (2001b), WEC (1995).
45. IPCC (1995).
46. The Japan Iron and Steel Federation (2002).

energy consumption would serve to drive innovation and adoption, so that larger reductions could be achieved.

Source:	**% increase in efficiency**
AEA (2000) (see note 1)	15%
Assmann, D. (2001) (see note 2)	38%
Institute of Energy Economics, Japan (2000) (see note 3)	6%
Bach, W. (1993) (see note 4)	48%
de Beer, J. et al. (1994) (see note 5)	31%
de Beer, J. (1998) (see note 6)	22% to 34%, depending on process
EWI/Prognos (1999) (see note 7)	55%
IPCC (2001b) (see note 8)	10% to 12%, updated to 30%
Polenz, C. (2001): (see note 9)	55 to 60%
Polenz, C. (2002) (see note 10	60%
Price, L. et al. (2001) (see note 11)	19% to 45%
Worrell, E. (1994) (see note 12)	40% to 50%

Note 1: Cost-effective saving potentials with existing best-practice (no BOF or hotstrip mill).
Note 2: Based on a collation of other studies.
Note 3: 1996 estimate of the technical reduction potential.
Note 4: 1990 to 2020 reduction of about 48% (better processing, higher share of electro steel, strong reduction of pig iron.)
Note 5: 1990 to 2015 economic reduction options of about (blast and basic oxygen furnace, heat recovery, hot strip mill, etc.).
Note 6: Primary steel making 34%, direct reduction 22%, scrap based mills 30% .
Note 7: 1995 to 2020 reduction of about 55% (better processing, higher share of electro steel, reduction of pig iron).
Note 8: Current technical potential reported as 10%–12% in the iron and steel industry. Increased to 30% after contact with the author.
Note 9: Technical potential (depends on the fuel type).
Note 10: Summarised international iron and steel studies, made some calculations and estimated a technical potential reduction of up to 60%.
Note 11: Brazil 19%, China 45%, India 45%, Mexico 40%.
Note 12: Techno-economic potential.

Table 1 : Energy efficiency potentials of the steel sector from various studies.

4.1.12) Other industries

There are still many other industries that are not included in the sub-sectors mentioned above. Efficiency improvement potentials are hard to investigate due to the variation within this sub-sector. Therefore, a simple estimation based on plausibility was made for this study, which is quite sufficient for such a long-term reflection. The shown reduction potentials represent the average of the entire industry sector apart from ‘other industries’ and reduced for surety to 20%.

4.1.13) Summarising the Results for the Industrial Sector in Japan

Summarising the different studies about European energy efficiency potential as shown in Table 1 shows a summary of the different studies of European industries' current energy efficiency potential.

As previously mentioned, Japanese industry in general is the most efficient in the world; therefore, the potentials mentioned in Table 2 were adapted and reduced in certain cases. Some sectors where analysed more in detail (e.g. Iron and Steel, lighting). To calculate the efficiency difference between Europe and Japan a detailed analysis and comparisons by Ministry of International Trade and Industry (???) (chemical, iron/steel, cement) was used. With that data the weighted average difference in efficiency can be calculated as 13% for the entire industry (based on the energy consumption of each of the three sectors). That means that the potentials mentioned were reduced by these percentages to achieve the Japanese reduction potentials in the Table 3, "Energy saving potentials in Japanese industry (percentages compared to 1999)".

Figure 4, "Final energy demand per industrial sub-sector 1999 and ERJ Demand Model" shows the current (1999) and potential reductions identified by the ERJ Demand Model. The greatest absolute savings of 758 PJ were seen in the chemical industry due to the measures described above. The greatest percentage reduction of over 50% was seen in agriculture, mainly due to fuel savings.

Energy Saving Potentials (Europe)							
in %							
	Coal	Coke	Oil	Nat. Gas	Geothermal	Other Ren.	Electricity
Agriculture, Forestry and Fishery			60		20		50
Mining Industry			48				36
Construction Industry			27				35
Food and Tabacco			54	53			38
Fibers	64		63	61		40	39
Paper, Pulp and Print	60		62	61		50	53
Chemical Industries	48	48	48	48		30	50
Ceramics and Cement	47	47	46	45			41
Iron and Steel	20	55	38	37			15
Non-Ferrous Metal	28	28	27	26			45
Metal and Machinery	65	65	66	65			42
Other Industries	39	39	39	39			39

Table 2 : Energy saving potentials in European industry (percentages compared to 1999)

Energy Saving Potentials (Japan)							
in %							
	Coal	Coke	Oil	Nat. Gas	Geothermal	Other Ren.	Electricity
Agriculture, Forestry and Fishery			52		17		44
Mining Industry			42				31
Construction Industry			23				30
Food and Tabacco			47	46			33
Fibers	56		55	53		35	34
Paper, Pulp and Print	52		54	53		44	46
Chemical Industries	35	35	35	35		22	37
Ceramics and Cement	42	42	41	41			37
Iron and Steel	10	48	29	28			4
Non-Ferrous Metal	24	24	23	23			39
Metal and Machinery	57	57	57	57			37
Other Industries	34	34	34	34			34

Source: ERJ.

Table 3 : Energy saving potentials in Japanese industry (percentages compared to 1999)

Total Consumption

in TJ

	Coal	Coke	Oil	Nat. Gas	Geothermal	Other Ren.	Electricity	Total Final Demand
Agriculture, Forestry and Fishery			426,131		4,146		13,568	443,845
Mining Industry			22,906				8,082	30,988
Construction Industry			174,456				4,146	178,602
Food and Tobacco			84,045	48,953			98,409	231,407
Fibers	1,131		89,866	8,333		1,926	29,606	130,862
Paper, Pulp and Print	51,089		118,844	30,067		94,430	127,052	421,482
Chemical Industries	28,434	5,905	1,803,894	80,109		1,340	234,925	2,154,607
Ceramics and Cement	209,213	16,415	165,034	15,787			78,894	485,343
Iron and Steel	397,655	882,328	119,472	60,427			284,883	1,744,765
Non-Ferrous Metal	5,109	8,417	48,157	15,452			69,556	146,691
Metal and Machinery	4,439	4,439	42,965	78,141			295,645	425,629
Other Industries	3,099	16,039	619,054	46,399			249,330	933,921
Total Industry	700,169	933,543	3,714,824	383,668	4,146	97,696	1,494,096	7,328,142

Source: EDMC (2001).

Table 4 : Final energy demand of Japanese industry (1999)

Energy Demand Industry

in TJ

	Coal	Coke	Oil	Nat. Gas	Geothermal	Other Ren.	Electricity	Total Final Demand
Agriculture, Forestry and Fishery			202,578		3,424		7,642	213,644
Mining Industry			13,341				5,551	18,892
Construction Industry			133,476				2,883	136,359
Food and Tobacco			44,561	26,381			65,875	136,817
Fibers	501		40,610	3,911		1,256	19,561	65,839
Paper, Pulp and Print	24,420		54,740	14,110		53,353	68,468	215,091
Chemical Industries	18,471	3,836	1,171,810	52,039		1,047	149,177	1,396,380
Ceramics and Cement	120,716	9,472	96,710	9,393			49,782	286,073
Iron and Steel	359,220	461,318	84,546	43,419			272,833	1,221,336
Non-Ferrous Metal	3,864	6,367	36,845	11,957			42,325	101,358
Metal and Machinery	1,929	1,929	18,294	33,952			187,616	243,720
Other Industries	2,049	10,604	409,297	30,677			164,848	617,475
Total Industry	531,170	493,526	2,306,808	225,839	3,424	55,656	1,036,561	4,652,984

Source: ERJ.

Table 5 : Final energy demand of Japanese Industry, ERJ Demand Model

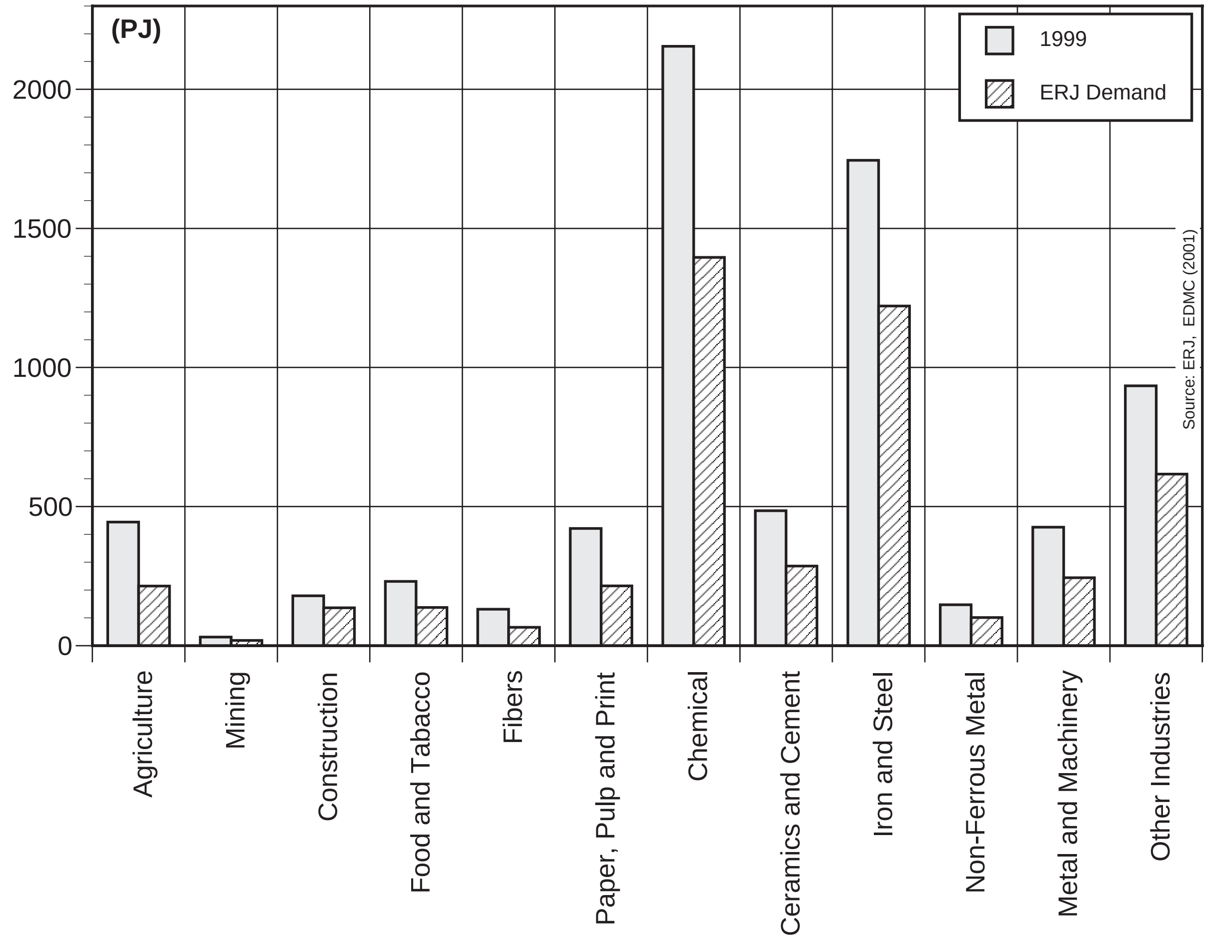

Figure 4 : Final energy demand per industrial sub-sector 1999 and ERJ Demand Model

4.2) Residential

The residential sector, which in 1999 consumed 14% of the total final energy supply, reduced its energy use by over 50% in the ERJ Demand Model.

Better analysis was available for the residential sector than for industry, as the range of technologies used is not as diverse. End-use areas of energy demand include mainly heating, cooling, cooking, lighting, hot water and motive power.

In order to determine reductions in residential energy demand, the logical starting point was to study improvements in house design and construction. A number of examples were found in Europe. The Enquete Commission of the German Parliament investigating environmental house design found potential energy reductions of 90% for Germany <47>. Improving building standards, using solar architecture and better air conditioning techniques resulted in large reductions in

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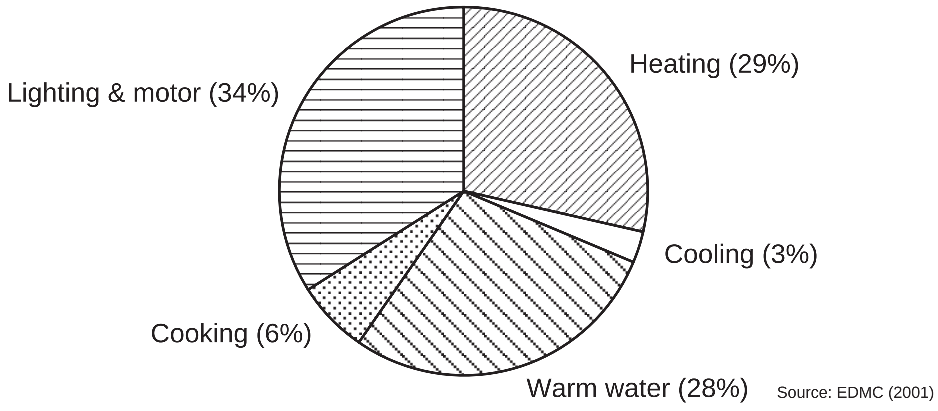
[47] Final Report Enquete Commission of the German Bundestag (2002)

energy demand. Other international comparisons of heating standards and construction possibilities also showed that in countries with moderate climate conditions similar to Japan, building standards show potential improvements of about 90% compared with today's average. In the case of Japan and other countries in the region, an improvement potential of only 73% was estimated. For achieving these potentials, Pfahl and Polenz only assumed existing construction options such as better insulation, advanced windows etc. and discussed their results with local experts.



Source: EDMC (2001)

Figure 5 : Residential final energy demand in 1999

The savings potential for cooling represents only a part of technical improvements of air-conditioners. The value represents some revisions of Japanese appliance energy efficiency standards done by Murakoshi, C. et al. (1999) from the Jyunkankyo Research Institute (JYURI) and especially Nagata, Y. (2001) from the Central Research Institute of Electric Power Industry (CRIEPI).

Specific Consumption

in kWh/m^2

	Electricity	Oil	Gas	Coal	Bioenergy	Solar	Total
Heating	4.8	28.8	6.8	0.0			40
Cooling	3.9						4
Water	2.7	20.7	14.4	0.3		2.1	40
Cooking	2.1	2.5	4.4		0.1		9
Lighting & motor	48.1						48
Total	62	52	26	0	0	2	142

Note: average size per household: 90 m^2. Source: ERJ.

Table 6 : Specific energy demand in the Japanese residential sector (1999)

Total Consumption

in TJ

	Electricity	Oil	Gas	Coal	Bioenergy	Solar	Total
Heating	73,617	442,260	104,626	326			620,830
Cooling	59,792						59,792
Water	40,740	317,474	221,851	4,012		31,815	615,892
Cooking	31,641	38,760	67,107		879		138,387
Lighting & motor	738,966						738,966
Total	944,756	798,494	393,584	4,338	879	31,815	2,173,867

Source: Handbook of Energy & Economic Statistics in Japan (EDMC 2001).

Table 7 : Total energy demand in the Japanese residential sector (1999)

The next area of study was to optimise household appliances by introducing best available technologies. This was achieved by making a detailed analysis of energy demand, actual standards and best available technologies in more than 150 countries<48>. The results of the study were then used as the basis for comparison against current Japanese demand in the area of household technologies in order to calculate demand potentials.

Improving burner performance could lead to a decrease of cooking fuel/electricity demand between 11% and 14% in Japan. UNDP (1997) estimated even higher potentials (based on a study of the US Office of Technology Assessment) as well as German experiences and estimations <49>. WEC/IIASA (1998) also showed higher reduction options between 15% and 20%. Compared with the actual Japanese situation and Japanese estimates, the indicated saving potentials seem to be feasible, but still conservative.

Energy Saving Potentials

in %

	Electricity	Oil	Gas	Coal	Bioenergy	passive Solar
Heating						73
Cooling	40					
Water	8	27	30	7		
Cooking	11	14	11		47	
Lighting & motor	53					

Source: ERJ.

Table 8 : Energy saving potentials in the Japanese residential sector in % compared to 1999.

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48. Pfahl, S. (2001).
49. Pfahl, S. (2001), Prognos/EWI (1999), Wolters, D. (2001).

Energy Demand Residential/Households					
in TJ					
	Electricity	Oil	Gas	Coal	Total
Heating					115,221
Cooling	35,875				35,875
Water	13,349	87,305	61,720	1,313	163,687
Cooking	28,160	33,334	59,725		121,219
Lighting & motor	347,314				347,314
Total	424,698	120,639	121,445	1,313	783,316

Source: ERJ.

Table 9 : Final energy demand of the residential sector, ERJ Demand Model

Water heating, electric appliances and lighting were identified as the most important energy consumers due to Japanese climatic conditions. Highly efficient lighting, efficient motors, a better match between motor, pump, piping and pumping demand, and best available refrigerators lead to an decrease of about 53% in the electricity consumption of households. Specific electricity consumption was decreased by a factor of five simply by using high-efficiency lighting. Best practice refrigerators only need one eighth of today’s systems and air conditioners offer improvements of at least 40%, for example. Stand-by power was also seen as important. Many electrical household appliances such as TVs, VCRs, audio equipment and computers consume hundreds of milliwatts to several watts of power when they are idle. Intelligent design avoids such a wasteful use of energy <50>.

The Figure 6, "Final residential energy demand 1999 and ERJ Demand Model in PJ" compares 1999 final energy demand in the residential sector to that in the ERJ Demand Model. The greatest absolute reduction in energy demand of 392 PJ was seen in lighting and motive power, and the largest percentage reduction of 75% was seen in heating.

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50. Murakoshi, C. et al. (1999), Nagata, Y. (2001), Pfahl, S. (2001), Polenz, C. (2002), UNDP (1997), Wolters, D. (2001).

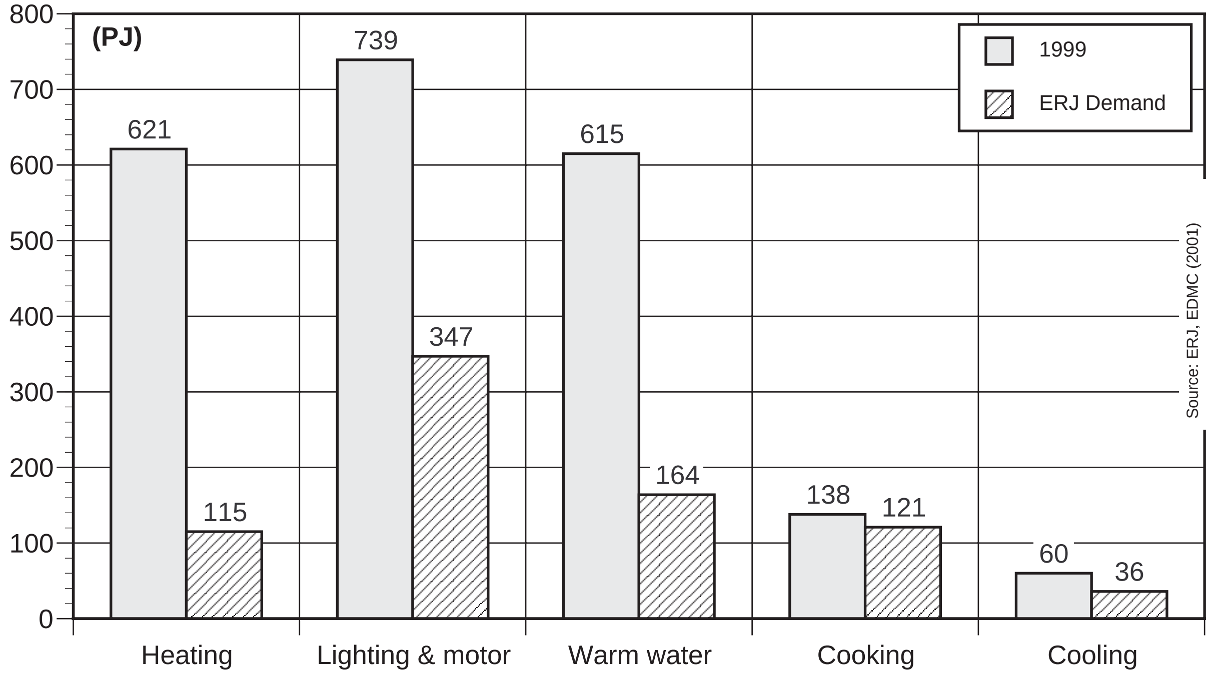
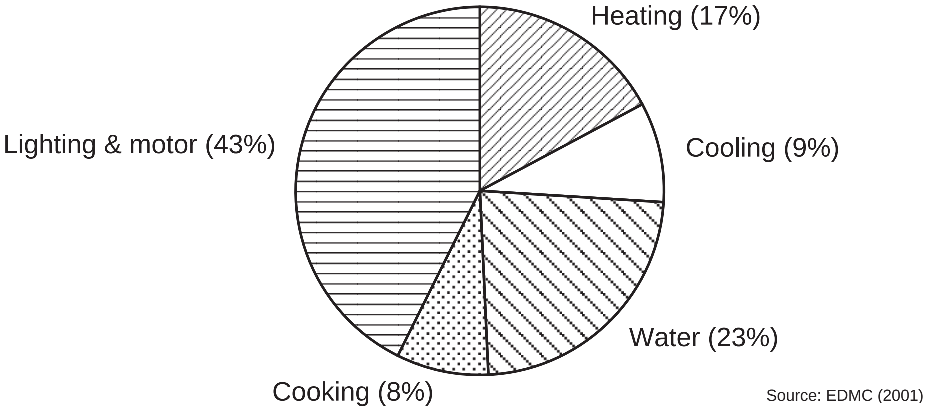


Figure 6 : Final residential energy demand 1999 and ERJ Demand Model in PJ

4.3) Commercial

The commercial sector consumes 12% of Japan's total final energy. A reduction of over 50% of the final energy consumption was found to be possible.

Branch-specific calculations were made in order to estimate the energy saving potential in the commercial and service sectors. Energetic analysis was more complex due to their diverse character, as all branches that did not fit readily into residential, industrial or transportation, such as handicrafts, trade or hospitals, were included here.



Source: EDMC (2001)

Figure 7 : Commercial energy demand in 1999

Specific Consumption

in kWh/m^2

	Electricity	Oil*	Gas**	Coal	Bioenergy	Solar	Total
Heating	5.0	60.5	6.6	1.0			73.2
Cooling	16.0	3.7	7.2				26.9
Water		40.2	22.7	4.0		4.5	71.4
Cooking			23.4		1.4		24.8
Lighting & motor	130.7						130.7
Total	151.7	104.4	59.9	5.0	1.4	4.5	327.0

* does not include LPG, ** LPG + Town Gas

Source: EDMC (2001)

Table 10 : Specific energy consumption in the Japanese commercial and service sectors (1999)

Total Consumption

in TJ

	Electricity	Oil*	Gas**	Coal	Bioenergy	Solar	Total
Heating	27,878	248,411	29,175	3,808			309,272
Cooling	93,768	21,838	42,312				157,918
Water		236,127	133,077	23,203		26,615	419,022
Cooking			137,172		8,189		145,361
Lighting & motor	766,867						766,867
Total	888,513	506,376	341,736	27,011	8,189	26,615	1,798,440

* does not include LPG, ** LPG + Town Gas

Source: EDMC (2001)

Table 11 : Total energy consumption of the Japanese commercial and service sectors (1999)

While some research into European branches exists no corresponding Japanese study could be identified. Another method of estimation was therefore used with different energy service demands, and analysed by first considering building construction and then applying BAT to appliances, similar to the methodology used in the residential sector. This led to a decrease of the total sectoral demand by 27% via improving building standards. By using the most efficient lighting systems, approximately 75% of electricity can be saved. The efficiency of motors, compressed air, pumps etc. also showed improvement potential, but not as much as with lighting <51>. The energy needed for cooling can be reduced by 30%.

Although it might be more difficult to reach a passive house standard for heating in the commercial sector, there are some new experiences that show this opportunity, e.g. Wagner Solar in Ger-

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51. ISI (2001), Nagata, Y. (2001), Pfahl, S. (2001), Prognos (1999), Tsuchiya , H. (2001), UNDP (1997), WEC/IIASA (1998), Wolters, D. (2001).

many. Pfahl, S. (2001) again estimated the saving potential for different regions. As one can see in the Table, the assumed reduction potential is much lower than in the residential sector (19% compared to 73%). That means it is at the low end of the efficiency potential and only represents today's state of the art but not the recent experiences of new approaches and buildings.

The specific consumption for electric cooling agrees with the results from Nagata mentioned above – it is again a reduction of about 40% due to the better performance of electric air-conditioners. For the same reason, the German Fraunhofer Institute ISI estimated a savings potential between existing cooling systems and the most modern techniques of about 32% based on oil and of about 51% based on gas. One has to take into account that higher saving rates could be reached by using solar architecture approaches. The result would be a strong decrease in the cooling demand. Until today little experience exists, which still shows possible potentials of more than 30 or 40%. However, we have chosen the more conservative assumption.

The best available technologies for water heating are very similar to the residential sector, only the percentage reductions vary because of different state of the art technologies. The BAT rates that one can find in the last table are mainly based upon Tsuchiya, H. (2001), Wolters, D. (2001) and Prognos (1999). Tsuchiya made specific calculations for Japan, Prognos made very detailed analysis for the German service sector and Wolters combined those results with the OECD Asian region situation.

The efficiency of cooking with natural gas is already very good in Japan compared with other countries or with other energy carriers such as electricity. Therefore, reduction potentials are quite low (approximately 11%) due to some performance improvements [52]. Only in the case of bio-energy (that has a low share compared with natural gas) are reduction potentials higher at 47% [53].

Energy Saving Potentials (BAT)

in %

	Electricity	Oil	Gas	Coal	Bioenergy	Passive Solar
Heating						42.7
Cooling	9.6	1.8	4.9			
Water		31.6	17.0	3.7		
Cooking			20.9		0.7	
Lighting & motor	50.0					

Source : ERJ.

Table 12 : Energy saving potentials in the Japanese commercial and service sectors in % compared to 1999

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[52] Pfahl, S. (2001), Prognos (1999), Wolters, D. (2001).

[53] UNDP (1997).

Energy Demand Commercial/Services						
in TJ						
	Electricity	Oil	Gas	Coal	Bioenergy	Total
Heating	5,289	47,133	5,535	723		58,680
Cooling	56,333	10,562	28,753			95,648
Water		185,429	99,756	21,712		306,897
Cooking			122,641		4,108	126,749
Lighting & motor	293,400					293,400
Total	355,022	243,124	256,685	22,435	4,108	881,374

Source : ERJ.

Table 13 : Final energy demand of the commercial and service sectors, ERJ Demand Model

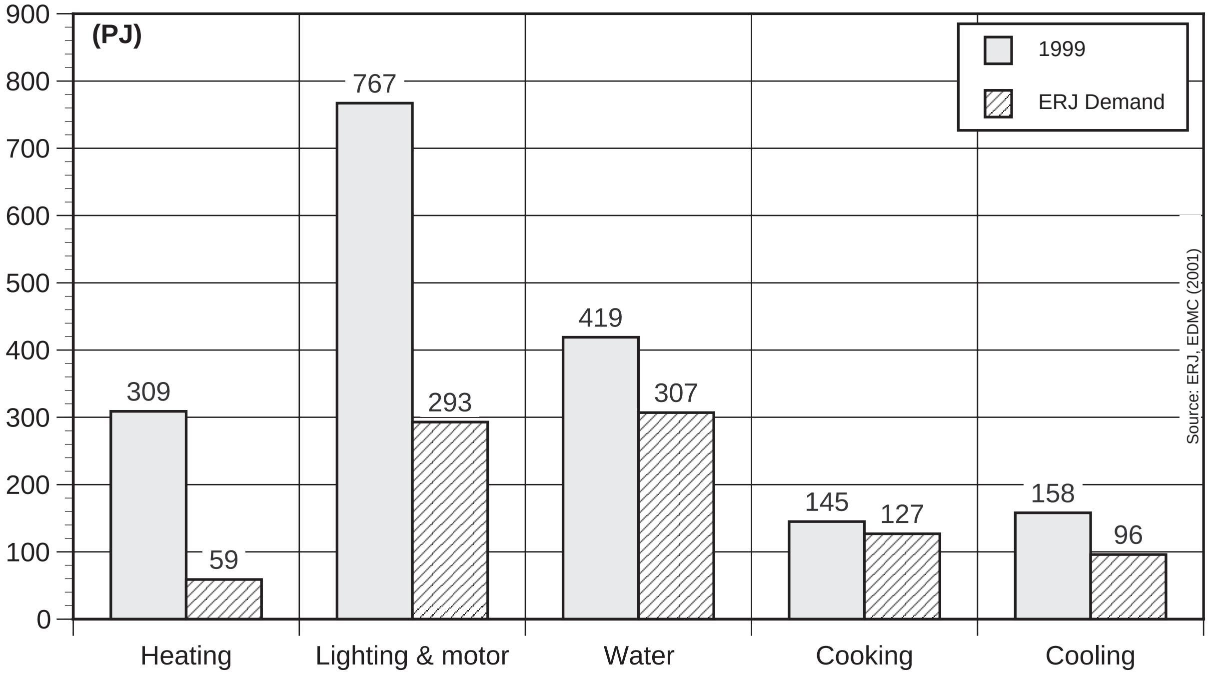


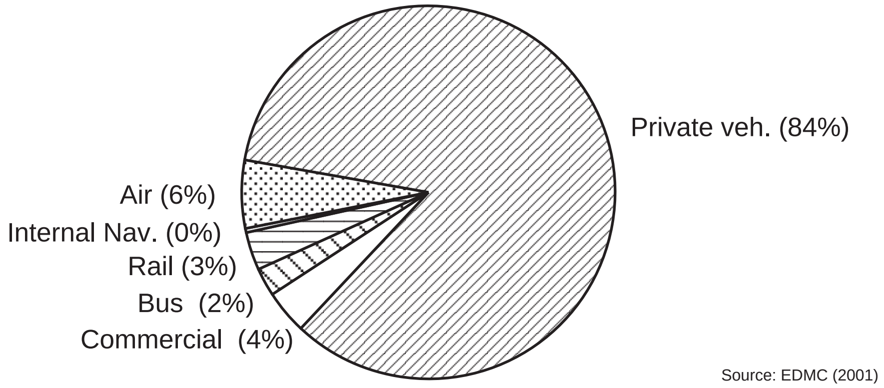
Figure 8 : Commercial final energy demand comparison

The greatest potential for reductions in electricity demand of 473 PJ was identified in commercial lighting and other electrical appliances, which were identified as more energy intensive than in the residential sector. The greatest percentage reduction of over 80% was seen in heating. Air conditioning was also seen as more relevant than in the residential sector.

4.4) Transport

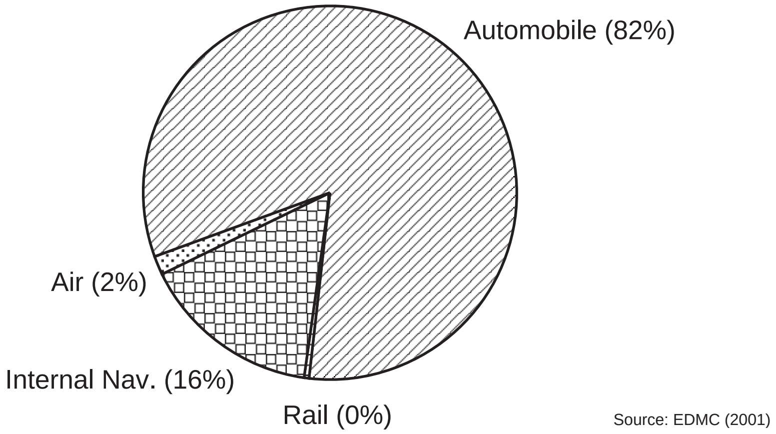
The transport sector consumes over a quarter of the total energy and could reduce its energy demand by a massive 70%.

Transportation was divided into passenger and freight transport. Energy in the transport sector is mainly consumed in the form of oil-derived fuels, whereas electricity used for rail transport constitutes only a small percentage.



Source: EDMC (2001)

Figure 9 : Passenger transport 1999



Source: EDMC (2001)

Figure 10 : Freight transport 1999

In Table 14, "Status of passenger and freight transport in Japan (1999)" the traffic volume and specific as well as total energy consumption for 1999 is shown.

Passenger Transport

1999

	Mio. Pkm	MJ/Pkm	PJ
Private vehicle	858,095	2.45	2098.0
Commercial	12,185	7.76	94.6
Bus	88,703	0.69	61.3
Rail	385,101	0.21	82.0
Internal Navigation	4,479	2.04	9.2
Air	79,360	1.85	146.5
Total	1,427,923	1.75	2493.2

Freight Transport

1999

	Mio. tkm	MJ/tkm	PJ
Road	306,156	3.73	1,140.7
Rail	22,541	0.26	5.9
Internal Navigation	229,432	0.94	216.1
Air	1,039	21.69	22.5
Total	559,167	2.48	1,385.6

Source: EDMC (2001).

Table 14 : Status of passenger and freight transport in Japan (1999)

The main improvements were seen in the use of the private car. Intensive research in this area has produced a number of options. Today’s vehicles have the potential to be much more fuel-efficient using conventional fuels or by conversion to the use of hydrogen as a fuel. Vehicles in Japan currently achieve 12.6 km per litre of fuel[54]. The demand for fuel-efficient vehicles in Europe and Japan has prompted manufacturers to develop and introduce vehicles that are between 40% and 60% more fuel-efficient than the average passenger car today[55]. Volkswagen has demonstrated fuel consumption figures of one litre per 100km with its latest experimental vehicle.[56] Vehicles already exist on the market, which use three litres per hundred kilometres. The specific consumption for private vehicles in the ERJ Demand Model is 40 km per litre of fuel. This value can be reached by reducing weight, air resistance, decreasing acceleration and rolling resistance, improved motor technologies and transmission, using lighter materials and hybrid technologies. All the technologies of the „Hypercar“ concept by Amory Lovins can also be taken into account, but are not used here.

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[54] EDMC (2001).

[55] Motor Vehicle Fuel Efficiency Initiative (2000).

[56] Volkswagen test not necessarily specific to Japanese conditions.

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Source: Greenpeace.

Figure 11 : The Greenpeace „SMILE“ car.

Fuel cell cars use electricity generated by a hydrogen-oxygen chemical reaction. Fuel will almost certainly switch to hydrogen, but even when fossil fuels are used to produce hydrogen, the efficiency is double that of the combustion engine. For cargo transportation, changing all vehicles over to hybrids reduced the energy demand in that sector by over 40%. For passenger transportation, changing all cars over to hybrid vehicles conserves 45% of the total passenger energy demand, and with the more efficient fuel cell technology the percentage rises to 54%<57>. Taking further possible measures into account<58>, specific consumption could be reduced by a factor of five to six.

Figure 12, "Transport energy reductions 1999 and ERJ Demand Model" shows that vehicles clearly offer the greatest energy reduction potential. The greatest absolute and percentage reduction of over 1,600 PJ or 77% was seen in private vehicles.

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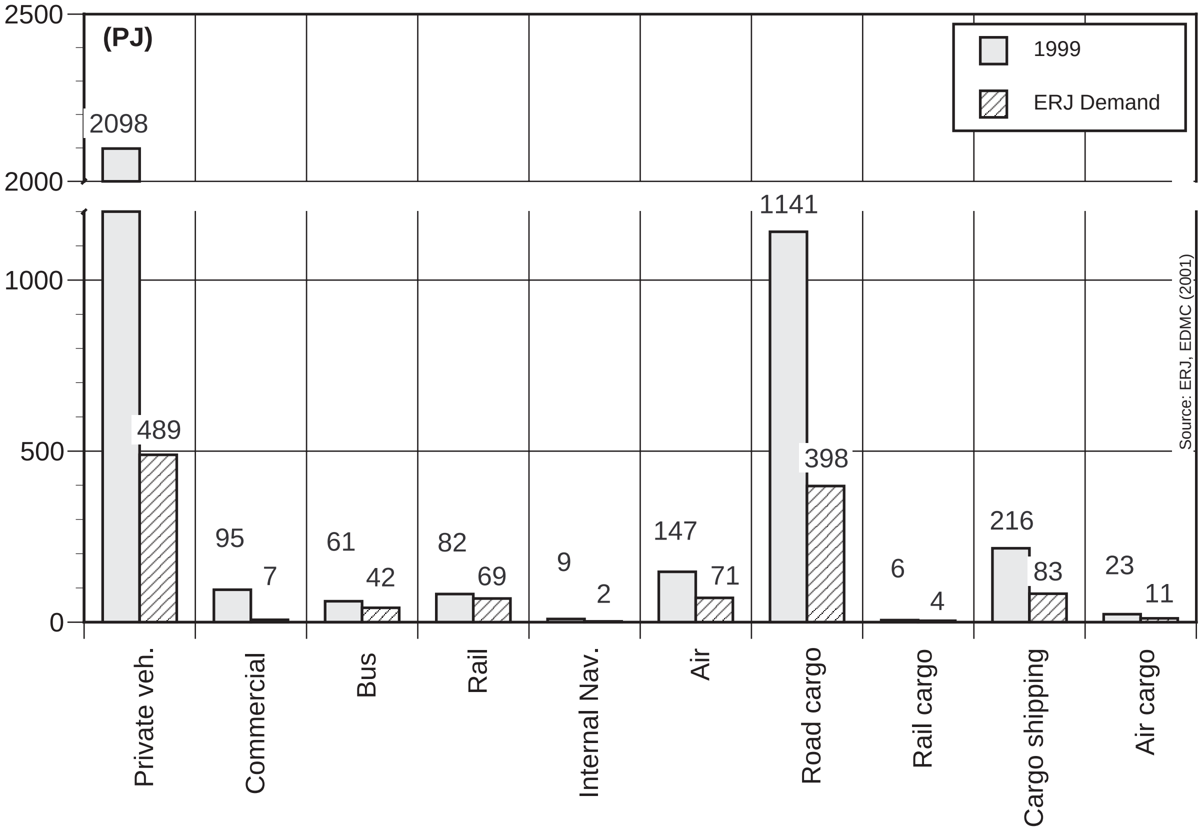
57. Tsuchiya, H. (2001).
58. Pfahl, S. (2001).



Source: ERJ, EDMC (2001)

Figure 12 : Transport energy reductions 1999 and ERJ Demand Model

4.5) Combining the Results – ERJ Demand Model

Japan is one of the most advanced countries in the world in terms of its energy efficiency but nonetheless, improvements using best available technologies are still possible and would result in a significant reduction in energy demand from over 15,000 PJ in 1999 to about 7,500 PJ in the ERJ Model.

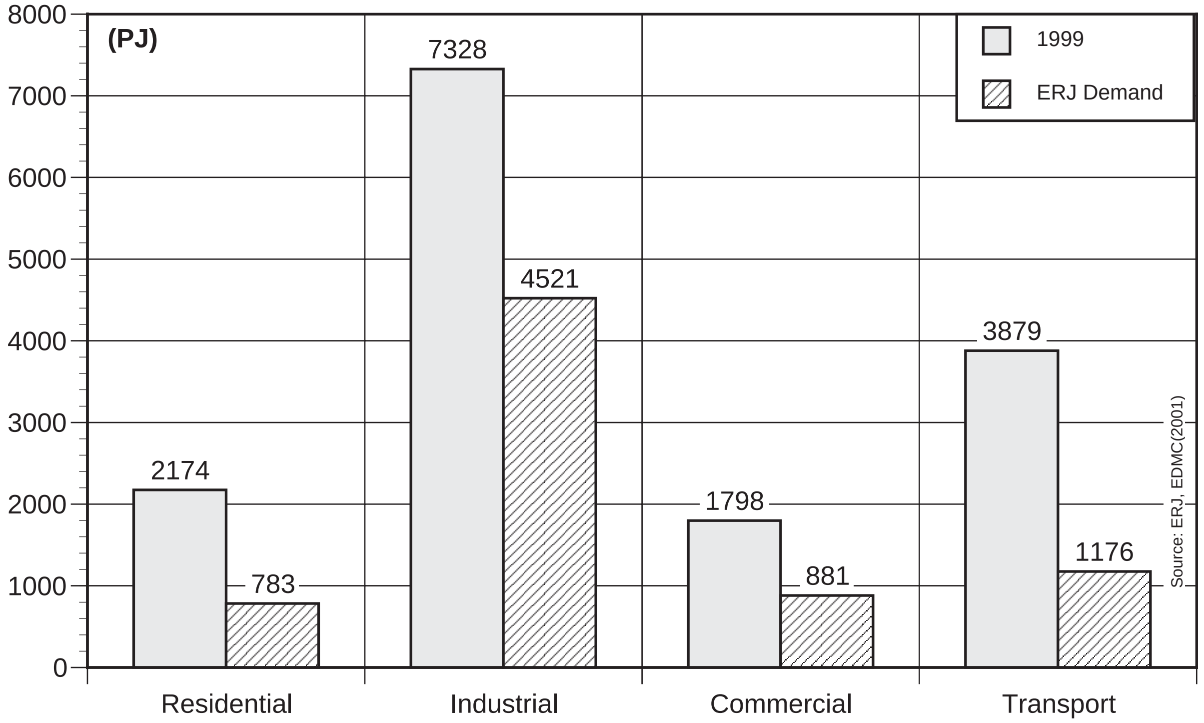


Figure 13 : Final energy demand, 1999 and the ERJ Demand Model

	1999		**Energy-Rich Japan Demand Model**		
	Energy in PJ	**Share**	**Energy in PJ**	**Share**	**Change**
Industry	7,328	48%	4,653	62%	-37%
Commercial	1,798	12%	881	12%	-51%
Residential	2,174	14%	783	10%	-64%
Transport	3,879	26%	1,176	16%	-70%
Total	15,179	100%	7,493	100%	-50%

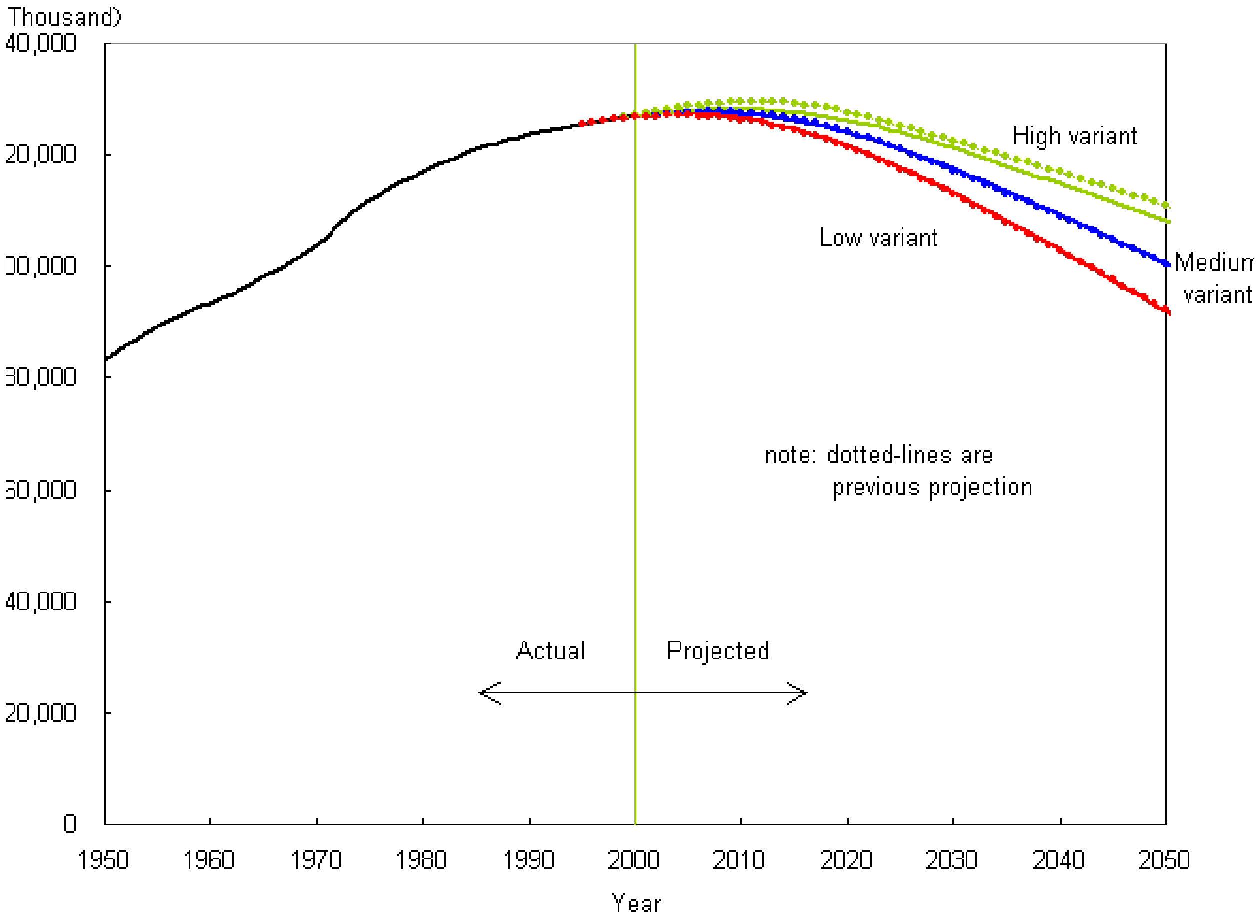
Source: EDMC (2001), ERJ.

Table 15 : The final energy demand 1999 and in the ERJ Demand Model

Our research revealed that with the same standard of living (in terms of energy services), a reduction potential of approximately 50% in energy demand exists in Japan. The greatest absolute reduction of over 2,800 PJ was seen in the industrial sector, with the largest percentage reduction of 70% in transport.

4.6) Greater Reductions Possible

The energy demand reduction envisaged for Japan is a conservative estimate of the potential savings as a number of factors that would have helped reduce demand were not included, such as, industrial changes and prototype highly efficient technologies. One factor that was assessed was that the total Japanese population is also expected to decline and the average age is set to increase<59>. Three scenarios consider this issue and are reported later in this report.



Source: National Institute of Population and Social Security Research (2001).

Figure 14 : Population projections. Japan 1950 to 2050

Employment in Japan is also moving away from the (higher energy consuming) industry sector towards the service sector. New jobs in information technology, working from home, changing travel patterns and new methods of communicating will also help to reduce energy demand<60>.

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59. National Institute of Population and Social Security Research (2001).
60. Statistics bureau and Statistics Centre, Ministry of Public Management, Home Affairs Post and Telecommunications (2001).

Japanese society is also changing its expectations regarding affluence, with a trend towards valuing free time and ‘sufficiency’ above wealth and possessions.

In addition, a huge energy saving potential exists with material optimisation, reduction, substitution, and product intensification, increasing product longevity and recycling. The concept of resource optimisation<61> is known as Factor 10. Schmidt-Bleek and the Factor 10 Club challenges industrialised nations to drastically reduce resources (and hence energy use). The concept closely follows the analysis of resource use and optimisation, known as MIPS (material input per unit of service), which demonstrates that a product function can have a much lower specific material requirement per unit of service.

Looking at the chemical and steel and iron industries, which are the biggest consumers in the industrial sector, a further reduction of 20% due to a decreased material intensity seems feasible.

Even the transport sector offers saving potentials that have not been outlined. The specific fuel consumption of private vehicles in the ERJ Demand Model was set to 2.5 litres per 100 km. Assuming a further reduction to 1.8 l/100km (a 28% reduction, compared to the ERJ Demand Model) results in saving almost 140 PJ of primary energy from fuels. Considering the same reduction for lorries saves another 110 PJ. In total a further reduction of fuel demand in the transport sector of nearly 250 PJ seems possible.

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61. Schmidt-Bleek, F. (1993), Factor 10 Club (1994).

5 The ERJ Supply Models

Area: about 373,000 sqkm
residential area: approx. 5 %
Agricultural area: approx. 14 %
Woodland: approx. 67 %

Population: approx. 127 million; on average 338 inhabitants per sqkm
Most populated: Kanto district, approx. 46 milion
Capital: Tokyo, 577 sqkm, approx 8.5 Mill. inhabitants

Figure 15 : Map of Japan

Any energy supply system must guarantee sufficient production and distribution of electricity, heat and fuels to meet the demand for energy at any time throughout the year, usually using different energy conversion technologies. The ERJ Supply Models use renewable energy sources, incorporating a wide variety of renewable energy technologies in order to supply the energy needs described in the ERJ Demand Model.

Energy is supplied in the form of electricity, heat or fuels. Heat and fuels have the advantage that they can be stored for later use and can be easily transported. So it is not necessary to consume heat and fuels immediately or in the place they were produced. Heat can be stored in thermal reservoirs and distributed via district heating networks. Both heat and fuels dissipate with time, which sets a limit to storage time and distribution distance. As for fuels from biomass or hydrogen, there is no limitation in storage time or in transport (depending on the fuel type - solid, liquid or gaseous) but storage losses must be considered.

The situation is completely different with electricity. The necessity of producing enough electricity, on demand and on time, makes this type of energy the most critical component in an energy supply system. While electrical transport via the public grid is quite unproblematic, storing electricity directly on a large scale is material- and cost- intensive. However, storage in batteries and accumulators can involve the use of toxic substances. Therefore this option is not considered here as it is not appropriate for a sustainable energy supply system. Indirect storage is used in the study by utilising hydrogen and pumped storage.

An energy supply system which is based solely on renewable sources increases the focus on timely energy provision due to the fluctuating nature of some renewable energy sources, such as solar and wind. Including such fluctuating sources into the public electricity supply means that the proportion of electricity produced by those sources might decrease suddenly. Of course electricity production from fluctuating sources can be estimated by weather forecasting but a portion of uncertainty still remains. Fortunately, there are other renewable technologies with the ability to deliver energy on demand; hydropower and geothermal power plants give direct access to renewable sources, cogeneration and other energy sources can use fuel from renewable sources (e.g. hydrogen or biomass).

5.1) Designing the Supply Model

The challenge in designing a reliable fully renewable energy system was to find a combination of technologies where the pros of some types balanced out the cons of the others. A reserve capacity is necessary as a backup for fluctuating sources, especially in the electrical system. This capacity can be minimised by designing a combination of renewable technologies where fluctuations in production match a varying demand, such that any fluctuations in supply never lead to electrical production that cannot meet the demand.

The focus in designing the ERJ Supply Models was therefore on the electrical subsystem, as this is the most (time) critical component of supply. The electrical supply model was designed to deliver electricity throughout the year using domestic Japanese energy sources as much as possible. The heat and fuels supplying system was then designed. Finally, variations on Scenario One were presented.

The supply of electricity, heat and fuels is described here in more detail:

5.1.1) Electricity

Sources capable of constantly producing electrical energy are most suitable for supplying the base load (the amount of energy that is always needed). Fluctuating sources can contribute to the peak load, but have to be supported by fast reacting power plants due to the uncertainty of energy production. Cogeneration plants are included as a highly efficient energy technology. Cogeneration plants use fuels to produce heat and electricity at the same time and with high efficiency. The capacity of cogeneration plants ranges from small units (CHP), capable of covering the heat demand of single households or small companies, to large plants that contribute to heat and electricity supply in industry. The mode of operation can be set according to the primary demand. If, for example, heat is most important, the production rate is determined by heat demand while the simultaneously produced electricity contributes to public electricity supply.

A reliable electrical supply system will sometimes produce more energy than is required. This is unavoidable due to the inclusion of renewable sources that might deliver much energy during times of low demand. These surpluses do not have to be lost however; they can be used to produce fuels such as hydrogen that can contribute to energy supply on time and in the form required by that sector.

The best possible combination of renewable sources, regarding electricity production and reliability, was determined by optimising the supply model using a computer simulation model. This model calculated and optimised the supply to meet the electricity demand. The optimisation process calculated installation based on the highest possible production of electricity from regional renewable sources while maintaining the rules of sustainability. Actual weather data from more than 150 weather stations in Japan was used in the simulation and the country divided into 12 regions in order to achieve a system, which was adapted to Japan's climate and geographical conditions for each technology.

The optimisation process used a bottom-up approach described as follows:

After defining an initial energy supply system, the simulation calculated the electricity production and compared the results to the demand. To prove the system's reliability in supply, electrical production and electrical demand had to be calculated and compared at short intervals. In the simulation this was achieved by calculating the electrical production over periods of a quarter of an hour and a 15-minute time-resolved electrical demand model (for details, refer to the chapter on simulation). The supply system was revised if any supply shortages were detected. This process was repeated until the mixture of technologies and locations of installation met the demand without shortages of electricity.

In Scenarios Two to Six, additional electricity producers were included to produce hydrogen using domestic sources, as Scenario One already covered all the required electricity.

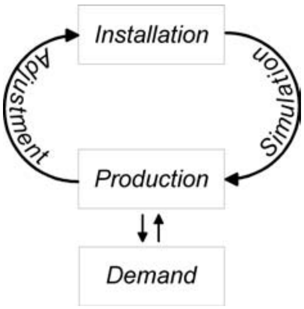


Figure 16 : The optimisation of installed capacities in the ERJ Supply Model

There is no demand management implemented in the supply models. The concept of demand management is to avoid peak loads in the supply system. This can be obtained by shifting a part of electricity consumption to times with generally low demand. While some electric appliances, such as refrigerators can be shut down for a while (modern refrigerators stay cool for hours without electricity), the operation of others can be delayed until the demand falls below critical levels. Demand management was excluded to keep the model's approach conservative and credible.

5.1.2) Heat

The limitations in transporting heat necessitate that any generated heat has to be consumed locally, that is near to the production plant. The heat supply structure reflects this fact, as consumers themselves also produce heat. The ERJ Supply Models keep the focus on the self-sufficiency of consumers but switch heat generation from fossil fuels to renewable sources. Therefore the ERJ Supply Models use cogeneration plants and solar-thermal collectors in the industrial, commercial and residential sectors.

Similar to fluctuating sources in electrical supply, the production rate of heat from solar-thermal collectors cannot be foreseen in terms of how much energy will be produced. Heat produced by solar-thermal systems has to be used immediately and sometimes heat production will far exceed heat demand. This is the point where heat storage becomes important. Heat can be stored for a long period of time, so it is not necessary to consume heat at the time it is produced. Of course the storage of heat is affected by storage loss, but it is even possible to store heat for several months with an acceptable loss in temperature and with acceptable prices. In the commercial and residential sector, this so-called long-term heat storage makes heat that is produced in summer available for use in autumn or even in winter, thus giving the opportunity of supplying a high share of heat demand from solar energy. Short-term and mid-term storage, capable of storing heat for periods up to one week or one month, can guarantee sufficient heat supply to buildings during times of bad weather conditions.

The main use for heat in the commercial and residential sectors is for warm water and heating. Solar collectors or small cogeneration systems (CHP) based on motors or fuel cells can easily produce the required temperatures. In the ERJ Supply Models these systems are combined in district heating networks with decentralised short-term heat storage and centralised mid-term to long-term heat storage. This approach increases system efficiency and minimises system costs.

Many processes in industry require heat at a temperature level above 150°C (high temperature heat). Producing heat at this temperature from solar energy would require systems that concentrate solar radiation. Such systems are expensive and not efficient under Japanese climate conditions. Therefore Scenario One only utilises cogeneration systems using steam turbines and heating plants for the production of high temperature heat. Both types of plants use fuels from renewable sources.

Low temperature heat (below 150°C) is sufficient for many applications in the industrial sector, such as hot water, heating and some industrial processes. In the ERJ Supply Model non-concentrating solar-thermal systems and motor-based cogeneration plants produce this heat.

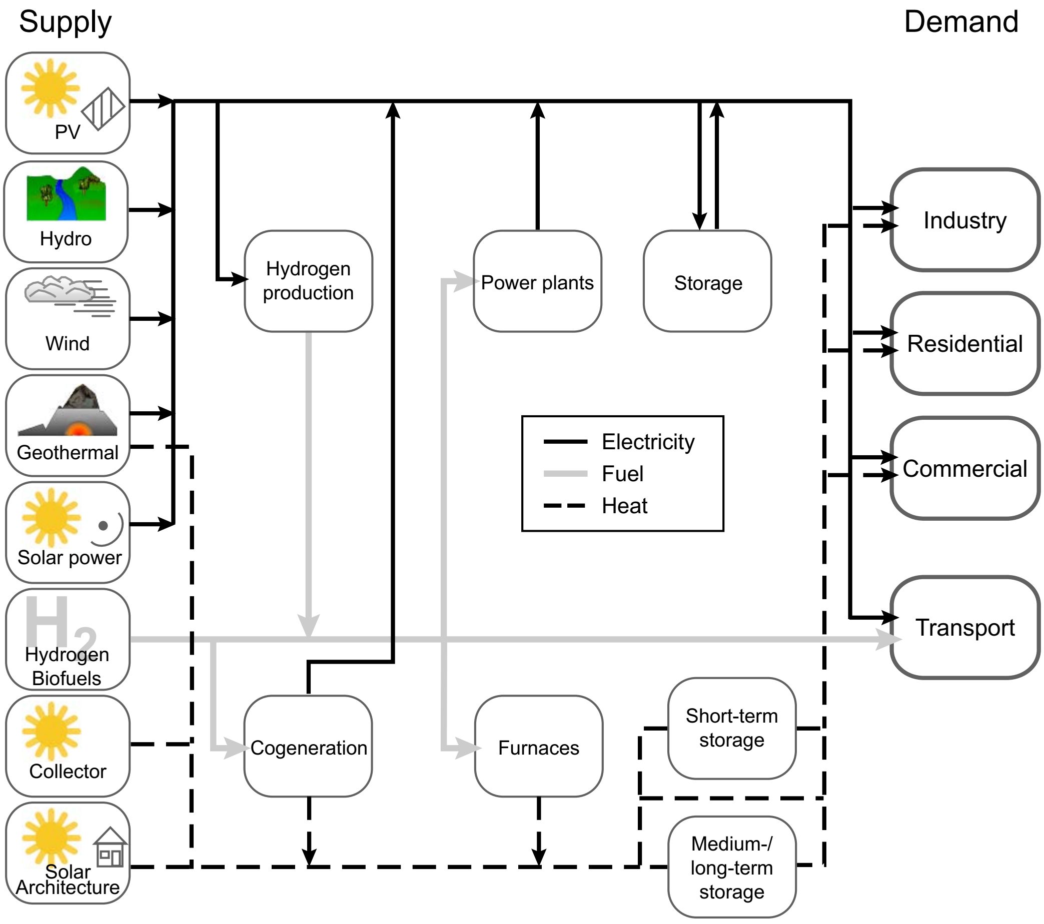
Cogeneration plants in industry are operated in two different modes. If electricity is most important for fabrication, the cogeneration plants are controlled to meet electricity demand, while the simultaneously produced heat can contribute to the heat demand. This mode of operation makes short-term heat storage necessary. The greatest demand for electricity and heat does not always occur simultaneously. Short-term heat storage can be used to make heat consumption independent of heat production in terms of time. Surpluses in heat production can be distributed via district heating networks to supply other industrial processes or buildings close to the site. If the demand for heat is vital for production, cogeneration plants are operated to produce the heat needed. Simultaneously produced electricity can contribute to the public supply if not needed for fabrication.

5.1.3) Fuels

The ERJ Supply Models consider fuels in all sectors although only the transport sector is strictly dependent on fuels. While the fuel demand in the transport sector is taken from the ERJ Demand Model, fuel consumption in the other sectors depends on the installed capacities and utilisation ratio of fuel consuming technologies in the ERJ Supply Models, for example cogeneration plants. The amount of fuel required was calculated by simulation.

Besides consuming fuels, the system itself produces fuels such as hydrogen by utilising surplus electricity from the supply system, and substitutes fuels that conventional systems need for warm water and heating by using heat from solar-thermal supplies. This approach has two major benefits: surpluses in electrical supply are not lost and the amount of fuels that must be applied from external sources is minimised.

The remaining demand for fuels (calculated as the total fuel demand, minus fuels substituted by solar-thermal systems and the system's hydrogen production) has to be covered by hydrogen or fuels from sustainably produced biomass. The amount quoted in the ERJ Supply Models represents the amount of hydrogen that is not covered by domestic sources in the different designs of the system. More fuels can be covered by sustainably produced domestic biomass, but the exact amount of biomass available in Japan was unknown at the time of publication. A total of six scenarios are calculated, which range from importing a percentage of the remaining demand through to a 100% regional production.



Source: ISUSI (2002).

Figure 17 : Structure of the ERJ Model

5.1.4) Grid Design and Reliability of the System

Renewable energy from large numbers of small-scale local generation sources would require a different type of distribution grid to the large-scale centralised energy supply network in place today. The focus would shift to decentralised energy sources with reliability of supply being dependent on a range of options for coping with intermittency such as increased interconnection, storage technologies and supply/demand management.

A diverse mixture of fluctuating sources, spread across all regions would tend to dampen the fluctuations, as changes in weather do not occur simultaneously in all areas and weather forecasts would allow for measures to ensure supply. Virtual power stations, constructed from a vast number of small suppliers, such as fuel cells in households, would combine, controlled by an Internet-like network, to act as a single unit to supply times of reduced supply.

In conclusion, grid reliability is ensured through a diverse network of decentralised, renewable energy sources, combined with flexible control and the optimal planning and co-ordination of resources. This is shown for Scenario One with the simulation of the electrical system.

5.2) Energy Sources used in the ERJ Supply Model

Scenario One offers the lowest amount of installations to ensure a reliable electricity supply. Other variations require a higher amount of installations in Japan. The renewable energy sources used include:

5.2.1) Solar Energy

The power of solar energy is defined by local solar radiation, which depends on geographical position and weather conditions. The utilisable energy depends on the area that can be used to absorb sunlight. In order to avoid the use of additional surface area, the primary locations for installation are already-used areas, such as roofs and façades. Solar energy can be used to produce electricity using photovoltaic panels and solar power plants, but also heat by using solar-thermal collectors.

Figure 18 : Kiyomino Solar Settlement (Japan); Source : Hakushin Corporation, Saitama.

The per capita installed area for photovoltaic and solar-thermal systems varies according to regional population density and climatic conditions. The maximum available roof area per inhabitant decreases as population density increases. This is due to the fact that in densely populated regions the share of multi-storey buildings and the average height of buildings are much higher than in less populated regions. Investigation into available and suitable areas for the installation of solar energy systems showed an average of nearly seven square meters per capita in the residential sector; the total suitable area in this sector amounts to about 880 km^2; the maximum is in Kyushu north with approximately 16 m^2 per capita and the minimum in Kansai with approximately four square meters per capita[62].

Region	**Suitable area (km^2)**	**Population [mill.]**	**Suitable area per capita [m^2/cap]**
Hokkaido West	32.5	2,841	11.4
Hokkaido East	15.0	2,841	5.3
Hokuriku	27.1	2,716	10.0
Tohoku West	58.0	5,499	10.5
Tohoku East	52.5	5,499	9.5
Chubu	90.3	12,892	7.0
Kanto	221.5	45,679	4.8
Kyushu North	109.4	6,723	16.3
Chugoku	56.4	7,732	7.3
Kansai	84.7	21,270	4.0
Kyushu South	103.4	8,041	12.9
Shikuku	29.1	4,154	7.0
Total:	879.7	125,889	7.0

Source: ISUSI.

Table 16 : Regional area in the residential sector that is suitable for the installation of solar cells and solar collectors (five percent of the dwelling area)

Solar energy can be used to produce electricity using photovoltaics and heat by using solar-thermal collectors. Just considering the residential sector alone, according to our research approximately 880 km^2 of the total roof area is suitable for installing systems that use solar energy. Scenario One includes approximately 400 km^2 (about 45% of the area mentioned above) of photovoltaic generators. This is equivalent to an average surface area of 3.2 m^2 per capita. The peak power of the installed photovoltaic systems amounts to about 60,800 MW; in 1999 approximately 200 MW of photovoltaic systems were installed in Japan. If the suitable area in the commercial and industrial sectors is also considered, 31% of the total available area in Japan was used for the installation of photovoltaic systems in Scenario One [63]. The installation of photovoltaic systems

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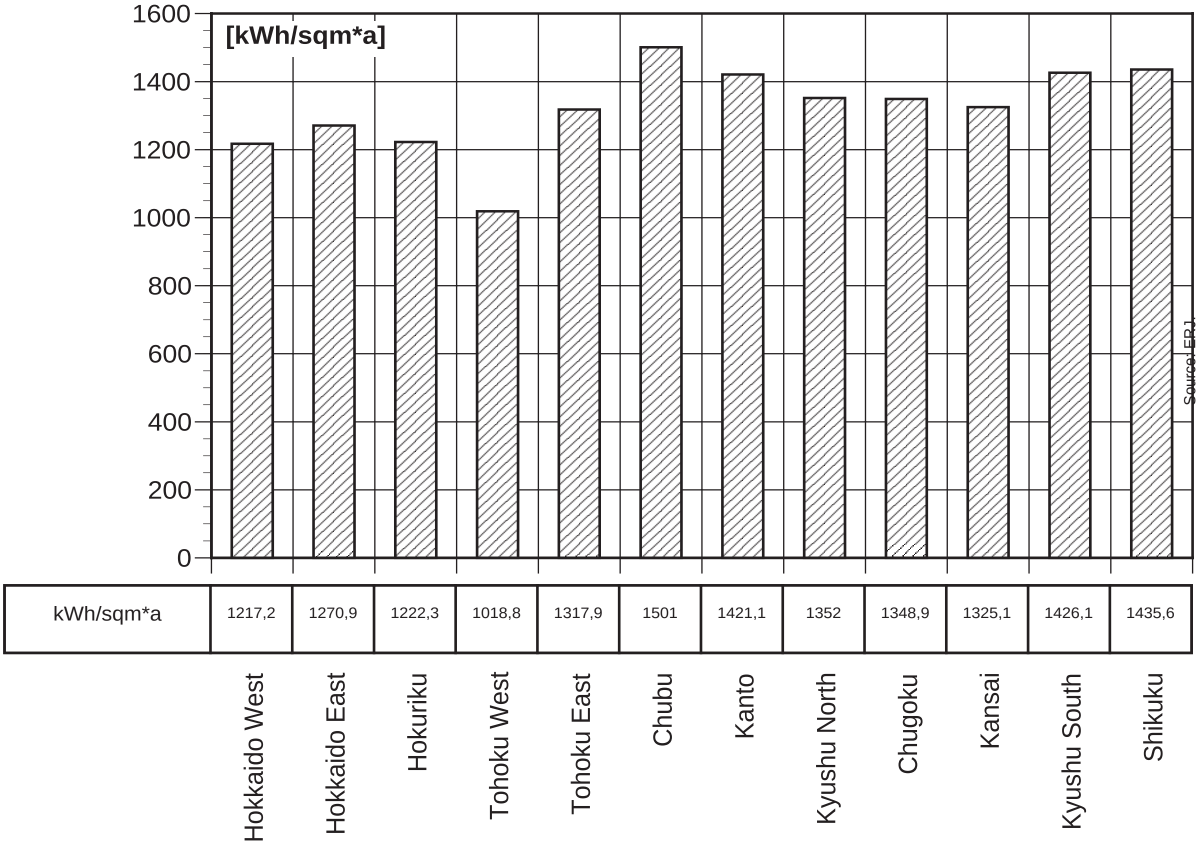
62. The available roof-area in Europe varies from about 7 m^2 to 9 m^2 per capita, depending on population density. Within Germany a range from approximately 5 m^2/cap to about 9 m^2/cap roof area is available. The German average is about 8 m^2/cap. Source: Lehmann, H. et al. (2003).

63. This is equivalent to about ten percent of the commercial and industrial sectors, 170 km^2 in the commercial and 260 km^2 in the industrial sectors.

was set according the available areas (depending on the population density described above) and the solar radiation data that was gained from 66 weather stations in Japan. The initial installation of photovoltaic systems, i.e. the installation that was chosen before any optimisation process was done, was set to 50 % of the suitable area in the residential sector. During optimisation, sites with high solar radiation were preferred for installation, but it was considered that enough free area had to be set aside for the installation of solar-thermal systems.

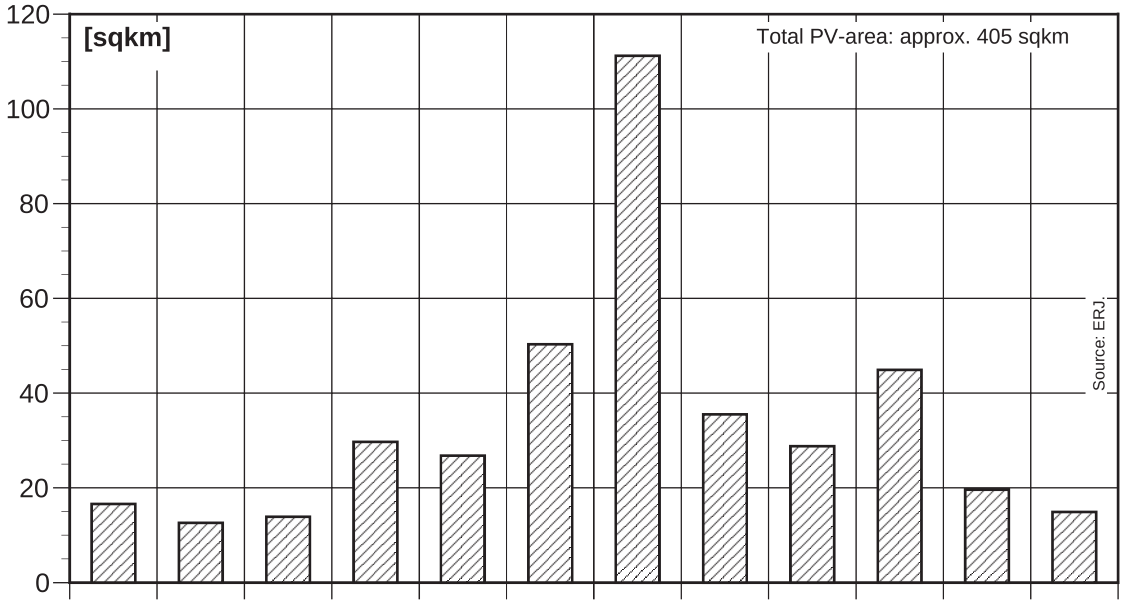
Some of the regions with good solar radiation are densely populated, e.g. Kanto and Kansai. This led to the situation that the optimum installation of photovoltaic systems and solar collectors regarding regional self-sufficiency and reliability would have exceeded the available area in the residential sector. In those regions the optimum installation of photovoltaic systems was maintained by also using suitable areas in the commercial and industrial sectors, such as roof areas of railway stations, commercial or industrial buildings. In addition, installation in remote areas was decreased, even if they were ideal, as not decreasing the installation would have led to significant regional surpluses due to the low demand in such sparsely populated regions, plus necessitating electricity transport over far greater distances. Fine-tuning of the installation was further optimised as a result of simulation runs in order to achieve an installation that best supported the whole supply system while minimising surpluses.



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
kWh/sqm*a	1217,2	1270,9	1222,3	1018,8	1317,9	1501	1421,1	1352	1348,9	1325,1	1426,1	1435,6

Figure 19 : Solar radiation in the different regions of ERJ Supply Model Scenario One as average values for the year 1999 (in kWh per m^2)

The photovoltaic area installed in Scenario One reflects the variation of population distribution in Japan. The per-capita installed area in the most populated regions (such as Kanto and Kansai, which have together approximately 67 million inhabitants) is significantly lower compared to most other regions. Only in Kyushu south, which is a less populated and remote region, is the amount of PV area similar to Kanto and Kansai.



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
sqkm	16,6	12,6	13,9	29,7	26,8	50,3	111,2	35,5	28,8	44,9	19,6	14,9
sqm/cap	5,8	4,4	5,1	5,4	4,9	3,9	2,4	5,3	3,7	2,1	2,4	3,6

Figure 20 : Installed area of solar cells in the different regions of Scenario One

The area of installed photovoltaic systems was not exclusively distributed amongst the available areas in the different sectors (residential, commercial and industrial). But as mentioned above, it was assumed that a fraction of the suitable area in the commercial and industrial sectors is used in densely populated regions with good solar radiation. Taking all the suitable areas together it is quite clear that the installation of photovoltaic systems can be more than doubled. This still does not include façade areas, areas on railway stations or parking places or even noise barriers alongside motorways that are well suited for the installation of photovoltaic systems.

One good example of integrated installation of photovoltaic systems is the headquarters of Kyocera in Japan. The roof and southern side of the building is equipped with a 214 kW photovoltaic plant, which saves at least 45,000 litres of fuel oil per year and in combination with a cogeneration plant makes the building self-sufficient in energy.

Source: XXX.

Figure 21 : The Kyocera Headquarters, which is self sufficient in energy.

The approach of installing solar-thermal collectors was different than with photovoltaic systems. Solar-thermal systems were installed with regard to district heating networks and consumer self-sufficiency. As described above, it is not possible to distribute heat in nationwide networks. The installation for each region was set to three square meters per capita. The actual installation varies according to the local building density. Less area for the installation of solar-thermal systems is available in locations with a high building density. Furthermore, some buildings might receive no solar radiation, making the installation of solar-thermal systems on these buildings useless. Under such conditions the heat supply is more focused on cogeneration and supported by the installed solar collectors. On the other hand, locations with a low building density offer a more suitable area for solar-thermal systems, so substantially increasing the potential for solar heat production; in this case the actual installation can exceed the average of three square meters by far. Here the heat supply is primary based on solar energy, while cogeneration is used to support the solar-thermal systems. All the heat-producing systems are combined in district heating networks with medium- to long-term heat storages.

Solar-thermal systems are used in the industrial and commercial sectors to support other heat producing technologies. In these sectors ten percent of the suitable areas (approximately 1,714 km^2 in the commercial and approximately 2,569 km^2 in the industrial sector) were used for installation, which is a quite conservative approach, especially with regard to flat roofs, which are in the majority in the industrial and commercial sectors.

The total area of solar-thermal collectors in all ERJ Supply Models is about 806 km^2, of which approximately 378 km^2 is on top of residential buildings (around 43% of the suitable area), about 170 km^2 is on commercial buildings and roughly 260 km^2 is on industrial areas; this is about ten percent of the available area in the commercial (approximately 1,700 km^2) and industrial (approximately 2,600 km^2) sectors.

Figure 22 : High efficiency solar thermal vacuum collector systems;
Source : Paradigma, Ritter Energie und Umwelttechnik, Karlsbad, Germany

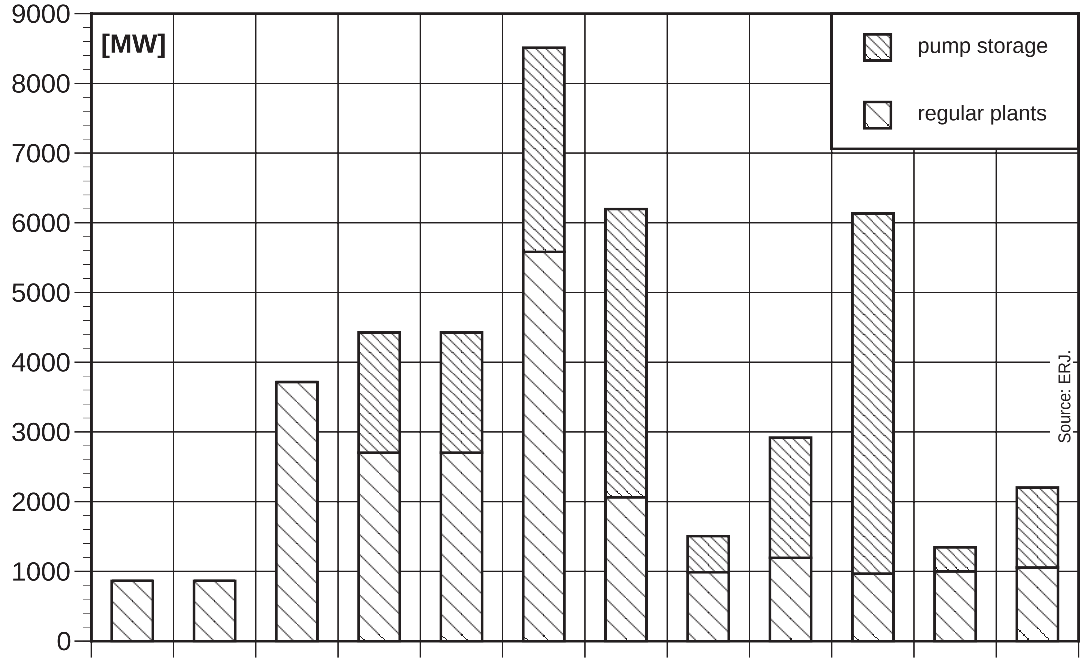
5.2.2) Hydropower:

The energy potential of hydropower depends on precipitation, mass flow rates, velocity and pressure. Hydropower depends on sites where natural conditions are conducive to energy production using water, that is high precipitation and a large mass flow rate or a large drop in altitude.

The utilisation of hydropower is, however, problematic. Large hydropower storage involves a massive destruction of existing ecosystems. Therefore, in all the ERJ Supply Models hydropower was restricted to existing plants. The only measure that was taken into account was the modernisation of plants, resulting in an energy increase of ten precent.

The installed capacity of hydropower plants in the ERJ Supply Models is about 24,000 MW. Another 19,400 MW comes from pumped storage plants, which are used for covering peak loads, i.e. during times when demand exceeds production of electricity by other sources. Pump storages are recharged during times when electrical production exceeds demand (see also the section on Fast Reacting Power Plants).

Although Chubu is the smallest region, the highest share of hydropower is located here (5,538 MW, which is about 25 % of the total hydropower). This reflects the good natural conditions this region offers for hydropower generation. This is similar to Hokuriku (northern neighbour to Chubu), which is the second-best region for hydropower. The lowest regional installation of hydropower is located in the two regions of Hokkaido with 862 MW each.

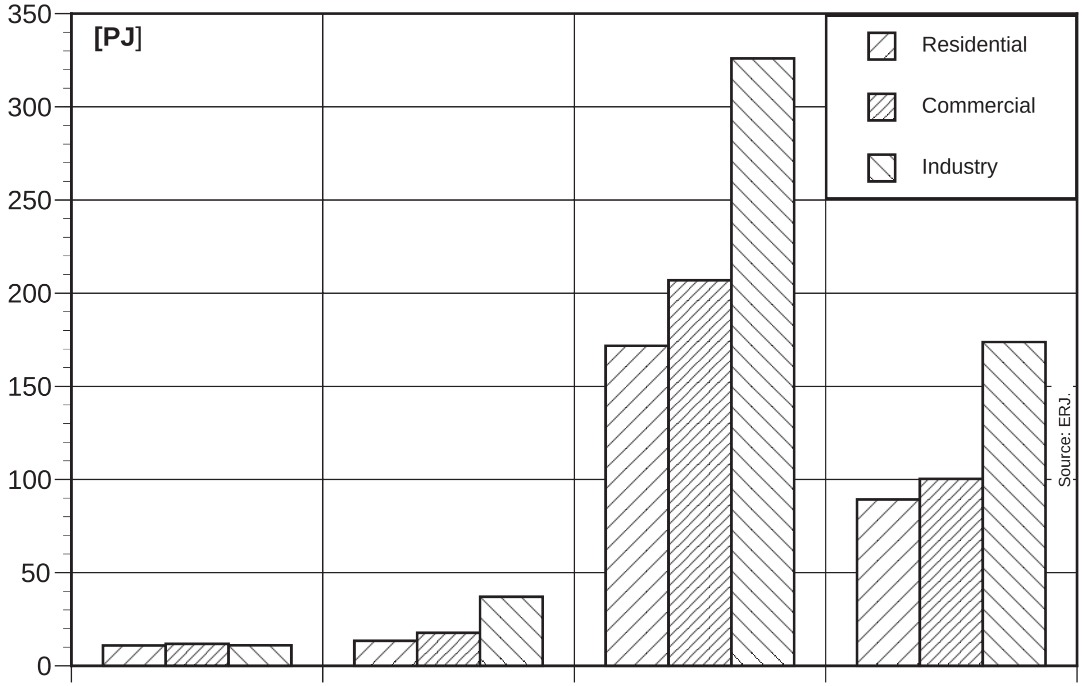


Source: ERJ.

	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
regular plants	862	862	3716	2702	2702	5583	2064	989	1194	966	1000	1054
pump storage	0	0	0	1723	1723	2928	4134	517	1723	5168	345	1148

Figure 23 : Installed hydropower in the different regions of the ERJ Supply Model

The highest amount of pumped storage plants is installed in Kanto with 4,143 MW and Kansai with 5,168 MW, representing the most populated regions in Japan (see Figure , "Note: These values were calculated, based on estimations of statistical data." below). Kanto and Kansai are also the most industrialised regions in Japan. As a result the electricity demand in these regions is high and supply’s reliability is more critical than in other regions. Any shortfalls in electrical supply would affect Japan’s industrial centres as well as about half of Japan’s population. Therefore these regions especially need reserve capacities to guarantee the reliability of the electrical supply system. There are no pumped storage plants in Hokkaido and Hokuriku as these regions are less populated and not comparable to Kanto or Kansai in terms of industrialisation; altogether Hokkaido and Hokuriku have approximately 8.4 million inhabitants.



	Hokkaido West	Hokuriku	Kanto	Kansai
Residential	10,91	13,39	171,72	89,3
Commercial	11,81	17,67	206,95	100,28
Industry	11,04	37,06	326,02	173,74

Note: These values were calculated, based on estimations of statistical data.

Figure 24 : Yearly electricity demand in the residential, commercial and industrial sectors of different regions in the ERJ Supply Model

5.2.3) Wind Energy

The energy provided by wind is determined by wind speed and so is defined by climate and geographical conditions. The proportion of the energy usable by wind turbines obviously depends on the number of wind turbines that can be installed. To keep the total installation of wind turbines on an acceptable scale, factors like the use of land, alteration of landscape and nature protection areas have to be considered. In general, sites close to the coast are most suitable for wind energy due to their exposed nature.

Several factors were considered regarding the installation of wind turbines. In order to determine the available area, the land area of each region, including population density were factored. For offshore installation, the maximum distance from the coastline was set to 30 km. Furthermore the choice of sites was made according to weather data that was derived from 153 weather stations.

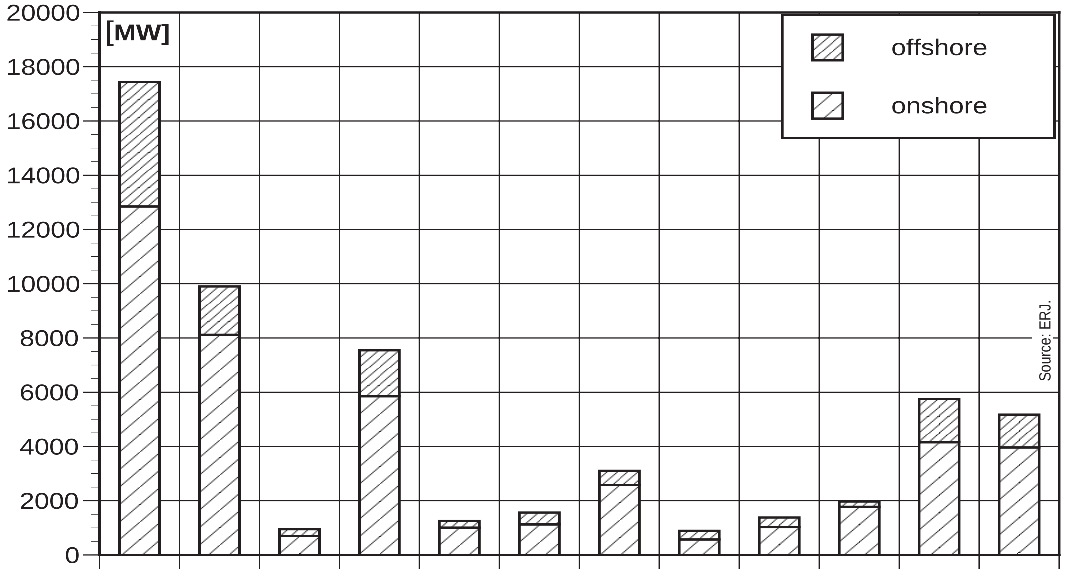
Three different types of wind turbines were chosen for installation in Scenario One:

- 1.8 MW plant with 108.6m-hub height and 82m-rotor diameter (not considered for offshore installation)
- 2.5 MW plant with 80m-hub height and 72m-rotor diameter
- 3 MW plant with 90m hub height and 80m rotor diameter

The algorithm used to find the optimum mix comprised of weather data, available areas and the different types of wind turbines to minimise the number of plants that are needed to achieve the required electrical output.

To keep the installation to an acceptable scale, the upper limits for the installation density were set according to the specific boundary conditions of each region (e.g. land area, population and length of the coastline). The maximum density for local installation was set to 0.5 plants per km^2 for onshore installation and 0.15 plants/km^2 for offshore installation. The installation in ERJ does not reach these limits in any of the regions. In reality wind turbines are not equally distributed over the available area. Some single wind turbines are installed at very good locations, but in general wind turbines are combined in wind parks, where the installation densities vary according to the type of plant that is used for installation. The size of wind parks is set to 25 wind turbines for onshore wind parks and 50 plants for offshore wind parks.

The area required by a single wind turbine determines the installation density in a wind park. The related values were chosen as follows. For onshore wind turbines it was assumed that the distance between the wind turbines that form a wind park must be at least five times the rotor diameter and ten times the rotor diameter for offshore installation, and thus about 7.5 to ten plants per km^2 are installed in onshore wind parks and about 2 to 2.5 plants/ km^2 offshore. This means that the distance between the wind parks is at least more than five km onshore and 13 km offshore. The nature of these limitations is more theoretical, because in the model the maximum installation density, which is in Kyushu south, reaches a value of 0.139 units/km^2 as a regional average. As a result the distance between wind parks in Kyushu South is more than 11 km on average. At minimum installation density (0.01 plants/km^2 in Kyushu north) the distance is approximately 45 km. For offshore installations the distance ranges from about 17km to 70km (installation densities from 0.009 to 0.106 plants/km^2).



	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikuku
onshore	12848	8116	703	5850	1010	1127	2576	572	1028	1778	4156	3962
units/sqkm	0,135	0,114	0,042	0,091	0,016	0,024	0,022	0,011	0,017	0,031	0,139	0,093
offshore	4583	1785	250	1693	245	437	526	320	355	191	1598	1211
units/sqkm	0,106	0,054	0,014	0,053	0,013	0,036	0,019	0,011	0,009	0,009	0,09	0,038

Figure 25 : Installed wind power in the different regions of Scenario One

In total, 27,029 wind turbines are installed in Scenario One, with 5096 offshore and 21,933 onshore. The total electric power is about 57,000 MW, which is less than five times more than was installed in Germany by March of 2003<64>. To get an impression of Japan’s wind power potential compared to Germany’s, the length of Japan’s coastline is about 29,000 km, whereas the German coastline is approximately 1,000 km.

The potential offered by wind energy is immense. Its potential globally even exceeds the estimated world electricity demand in 2020 by more than a factor of two. The Greenpeace study “Wind Force 12” showed that 12% of the world’s electricity demand could be covered by wind energy by the year 2020<65>.

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64. Bundesverband Windenergie e.V. (2002).

5.2.4) Geothermal Energy

Geothermal energy utilises heat from the earth’s core. Temperatures rise by about 3°C per 100m as you descend from the surface of the earth. In some locations, in so-called geothermal anomalies, high temperatures can be found relatively close to the earth’s surface. These heat sources are easy to exploit and can be used for the production of heat and electricity. The utilisation of geothermal energy requires a power plant to be built close to the geothermal source. This restricts exploitation to sources that are outside national parks and that can be used with minimal impact on the ecosystem.

According to the Institute for Energy and Total Engineering<66>, Japan’s geothermal sources located outside of national parks offer the potential for installing power plants with approximately 76,200 MW of electrical power. Scenario One contains about 22,900 MW of geothermal power plants (about 25% of the potential) for the production of electricity; in 2000 the installed capacity was approximately 550 MW<67>. The degree of utilisation in Scenario One is equivalent to approximately 7,000 full load hours a year, which is quite conservative, compared to nuclear power plants (with approximately 7,500 full load hours a year<68>).

As the distribution shows (Figure 26, "Installed geothermal power plants in the different regions of Scenario One"), geothermal energy production is concentrated to Hokkaido and Tohoku, with more than 5,000 MW each. Much less is installed in Kanto (approximately 2,000 MW), which is due to the densely populated and industrialised structure of Kanto. Only smaller installations are located in the other regions. This regional distribution is not mandatory and might be altered.

The use of heat pumps, which can utilise near-surface or deep geothermal heat, despite the fact that there is a very big potential, is not considered for the heat supply in the ERJ Supply Models.

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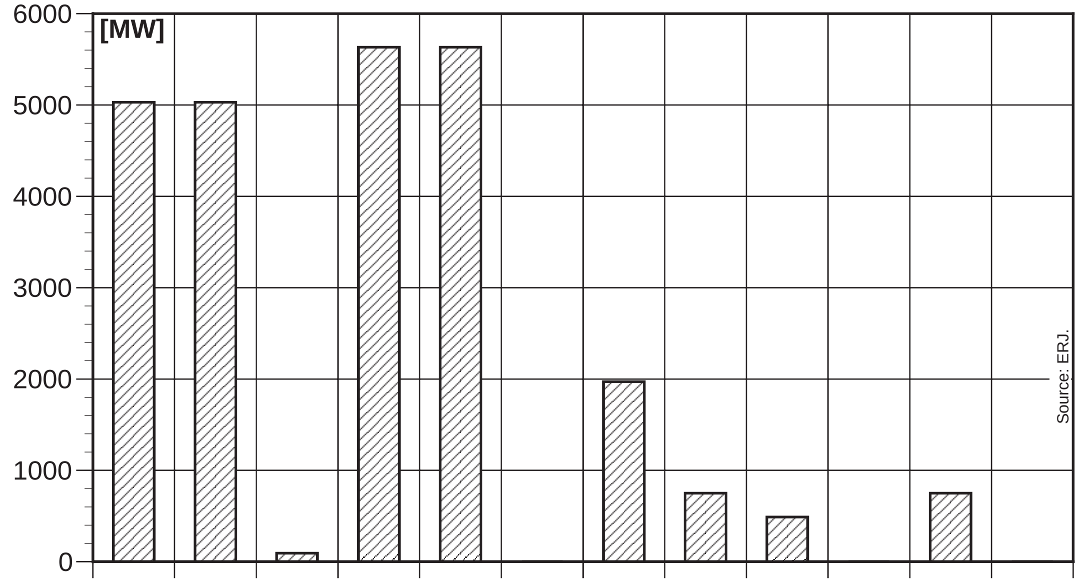
65. EWEA (2002).
66. NEDO (1989).
67. Lund, J. (2000).
68. Akademie für Technikfolgenabschätzung in Baden-Württemberg (1999).



Source: ERJ.

	Hokkaido West	Hokkaido East	Hokuriku	Tohoku West	Tohoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu Sout	Shikuku
rated output	5029	5029	93	5633	5633	0	1971	751	490	0	751	0

Figure 26 : Installed geothermal power plants in the different regions of Scenario One

5.2.5) Fuels from Renewable Sources

The oil economy, for so long the provider of apparently cheap fuels, will need to be replaced with renewable fuels. So what are our options for renewable fuels that can be supplied in great enough quantities? The main players here are bio fuels and hydrogen. Fuels from renewable sources can be produced from biomass (such as biogas in the form of methane) or hydrogen from the electrolysis of water (using renewable energy sources). It is important to note that biomass has to be produced under the rules of sustainability as described below.

Biomass

Although no biomass is included in all the ERJ Models, it is clear that it will play an important role in a future energy system. Biomass can be burned to produce electricity and heat in combined heat and power plants; it can be used to produce bio fuels (e.g. biogas) for vehicles. In addition, biomass can be stored and transported. Note: biomass mentioned below does not include energy recovery from waste incineration. The following describes the requirements for a sustainable biomass supply:

- Positive Energy Balance[69]

The net energy produced by the biomass cycle (that is released solar energy) must be greater than the energy used in its germination-to-generation lifecycle. That is, when all the energy from other sources used to produce, process and transport the biomass is aggregated, this must be less than the amount of energy that is derived from the combustion of the biomass. Only the energy derived above and beyond this threshold may be considered renewable.

- Carbon Neutral

The net (carbon) greenhouse gas emission of the biomass cycle used must be zero or negative. That is, the carbon, and carbon equivalent of nitrous oxides, methane and other greenhouse gases released to the atmosphere by the full germination-to-generation cycle must be less than, or equal to, the carbon absorbed or fixed by the biomass itself – including carbon removed or fixed within the soil, sequestration by forest or live crop, greenhouse gases emitted though land use change or net depletion, and greenhouse gases released due to transportation and production of fertilisers and pesticides.

- Biodiversity Impacts

Biomass production involves production over significant land areas, and this requires careful consideration of potential for biodiversity impacts. Biomass productions must aim to maintain and restore indigenous biodiversity, taking particular account of rare, threatened and endangered species and ecosystems, complement biodiversity conservation strategies, entail no conversion of natural ecosystems, and be guided by the results of environmental impact assessments and ongoing monitoring.

- GMO free

The biomass plants, or enzymes used in the processing of the biomass must not include genetically modified plants or other organisms. This includes agricultural and forestry residues as well as purpose grown ‘energy crops’ and their conversion to other energy forms.

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69. Many organic waste streams or residues do not meet the positive energy balance and carbon neutral criteria defined above. However it is useful to recognise that residues which were not designed to be energy sources may be useful sources of energy, which are otherwise wasted. In this case it may be appropriate to recognise that the extra energy/carbon, which has been spent in the processing has been expended for its primary purpose, not its waste value. Provided this energy has been expended for the primary purpose of the material, then it may be appropriate to neglect the energy balance and carbon balance prior to the time of processing when the waste stream is created.

- Sustainable Plantation/Agriculture

The processes for producing the biomass must be sustainable with respect to water, nutrient and mineral balances within the soil. Biomass production must be constrained to existing agricultural croplands and the restoration of degraded or abandoned land. The production process must also be socially sustainable and therefore responsible in terms of its social impacts. Specific criteria for land-use sustainability are contained within Greenpeace plantations policy documents (see http://archive.greenpeace.org/~forests/).

- Toxicity

The biomass conversion processes and its secondary effects (i.e. any non bio-organic substances processed along with the biomass) should not cause:

- Additional toxic matter – solid, liquid or gaseous
- Net increase in the toxicity of the matter
- A net increase of the impact of toxic materials with respect to the environment i.e. improved containment relative of the toxic matter, comparative to the input material
- External emissions that are not related to the carbon combustion process. Emission of pollutants that are related to the basic carbon combustion process such as nitro-oxidents and sulpher-oxidents (NOX and SOX) should be equal to best available technology levels

It seem that Japan has a substantial potential for sustainable produced biomass, but no accurate assessment of its scale is available.

Hydrogen

The issues of hydrogen production and infrastructure are discussed in more detail in Scenario One below. Hydrogen can be produced by a number of processes. The most sustainable process for the production of hydrogen is the electrolysis of water, which is energy intensive<70>. Electricity used for hydrogen production must come from renewable sources. A number of other processes are currently used for hydrogen production. A common method using steam reformation of natural gas, accounts for a large percentage of world production. Natural gas is a fossil fuel, which is a finite resource. This process also produces carbon dioxide and is therefore unsustainable.

Hydrogen can be used as a fuel for vehicles and for the production of electricity and/or heat. Hydrogen is used in cogeneration plants for generating electricity and heat in the ERJ Supply Models. Fast Reacting Power Plants (FRPP) are also used solely to produce electricity. In the ERJ Supply Models, fuel consumption and production are shown as the hydrogen equivalent in order

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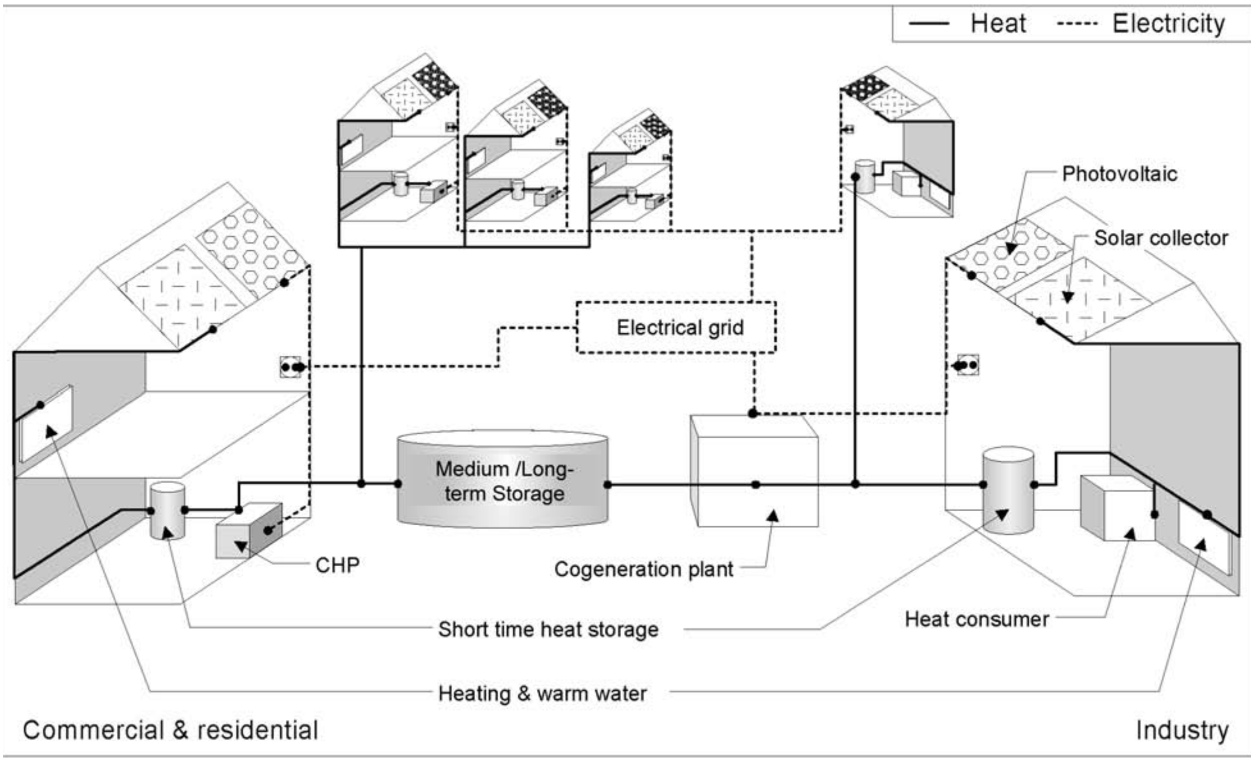
70. Hydrogen produced from the steam reformation of natural gas is not sustainable.

to easily calculate the amount of hydrogen required. The simulation determines the installation capacity of fuel-consuming plants in the electrical system. Surpluses in the electrical supply system are used for the production of hydrogen. The domestic production of hydrogen can be increased by the additional use of renewable sources, such as photovoltaic systems, wind turbines and solar power plants installed in remote areas used solely for producing hydrogen.

5.2.6) Cogeneration Plants

Cogeneration plants use fuels from renewable sources to simultaneously produce heat and power with high efficiency. The mode of operation can be adjusted to supply demand, either mostly for heat or for power. Surpluses can contribute to the public supply, whether heat or electricity, or be stored for use on demand as in the case of heat.



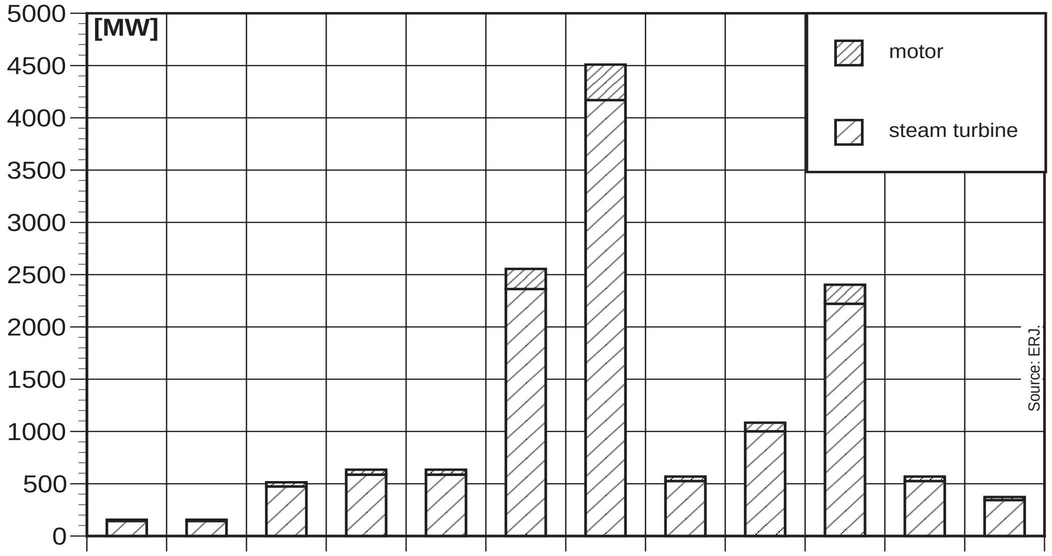
Source: ISUSI

Figure 27 : The use of cogeneration plants in the ERJ Supply Models (storage and solar systems are also shown)

The ERJ Supply Models use cogeneration plants in the industrial, commercial and residential sectors. Smaller systems installed in commercial and residential sector make use of motors or fuel cells. Larger systems are installed in the industrial sector. These systems utilise steam turbines if the heat output has to be at high temperatures, or motors for the production of low temperature heat and electricity.

The installed capacity of cogeneration plants in industry in the Scenario One is 22,900 MW electrical power. In 1999, the total installed capacity of cogeneration plants in Japanese industry was approximately 4,000 MW.

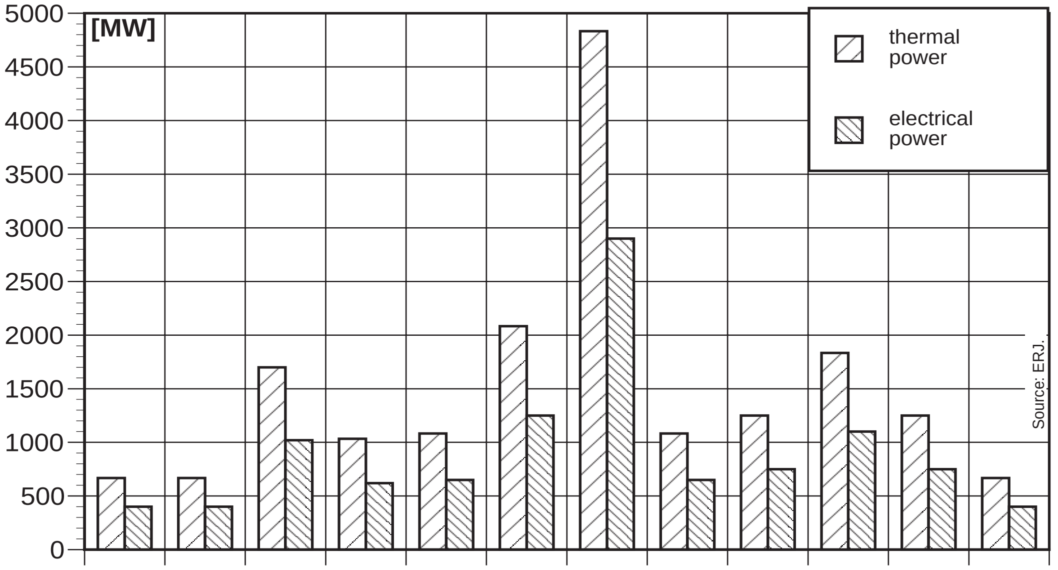
The most densely populated regions are the most industrialised regions. The distribution shows the connection between energy demand in the industrial sector and population distribution. The highest amount of industrial cogeneration is installed in Kanto, followed by Chubu and Kansai. Although Chubu is less populated than Kansai it is more industrialised. The reason is that Chubu is the region next to Kanto, which is the industrial centre in Japan.



Source: ERJ.

	Hokkaido West	Hokkaido East	Hokuriku	Tokoku West	Tokoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikiku
steam turbine	143	143	474	587	587	2363	4170	525	1001	2222	525	344
motor	12	12	39	48	48	192	339	44	83	182	44	29

Figure 28 : Electrical power of industrial cogeneration in the different regions of Scenario One



Source: ERJ.

	Hokkaido West	Hokkaido East	Hokuriku	Tokoku West	Tokoku East	Chubu	Kanto	Kyushu North	Chugoku	Kansai	Kyushu South	Shikiku
thermal power	667	667	1700	1033	1083	2083	4833	1083	1250	1833	1250	667
electrical power	400	400	1020	620	650	1250	2900	650	750	1100	750	400

Figure 29 : Electrical and thermal power of cogeneration in the residential and commercial sectors in the different regions of Japan in Scenario One

Cogeneration plants in the residential and commercial sectors are used in combination with solar-thermal systems. On locations with good conditions for solar heat production (enough available area, high solar irradiation) solar collectors are the primary source in heat supply. If the available area and/or the solar irradiation is not sufficient, cogeneration takes over the primary task in heat supply, while solar-thermal systems are used to support them. The scale of installation was chosen in order to guarantee a sufficient heat supply even during times with low solar irradiation and as a back-up for days or periods with unusual low outside temperatures.

The total installed electrical power in the commercial and residential sectors in Scenario One is nearly 11,000 MW; the installed capacity in Japan in 1999 was about 1,000 MW<71>.

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71. EDMC (2001).

5.2.7) Solar-thermal Power Plants

Solar-thermal power plants produce heat from the solar irradiation that then is converted into electricity using conventional power plant technologies. Because of the high temperatures, necessary for electricity generation in a conventional process, the solar irradiation is concentrated by parabolic solar collectors (so called ‘Solar Farm‘ concept) or gets focused on a cental absorber by a field of mirrors (‘´Solartower‘ concept).

Nine plants of the ‘Solar Farm‘ type have been built near Kramer Junction in Mojave desert, California, from 1984 to 1991.

Source: XXX.

Figure 30 : The Kramer Junction “SEGS” solar-thermal power plants

The total generation capacity of these plants is 345 MW. About 75% of the electricity is produced from solar heat, while the rest is supplied by conventional co-firing.

The first generation of “Solar Farm” power plants uses thermo-oil as heat transfer medium (to transport heat from the parabolic collector field to the heat circulation of the power generating part of the plant). Recent developments aim for the direct production if steam within the parabolic collectors, using water as heat transfer meduim, thus eliminating the need for potentially ground contanimating fluids.

While the ‘Solar Farm‘ concept has proved to be ready for the market, the ‘Solar Tower‘ concept is still in test stage, promising good performance especially for single big units.<72>

Solar-thermal power plants were used in scenarios Five and Six with different amounts for the installed capacities. Scenario Five contained about 600 square kilometers of solar-thermal power plants and it was 370 sqkm were installed in scenario Six.

5.2.8) Fast Reacting Power Plants

Any electrical supply system is exposed to the risk that a proportion of electricity production suddenly fails. This might happen due to malfunction of a power plant or sudden decrease in electricity production of fluctuating sources. This might lead to the situation that demand exceeds production. Fast Reacting Power Plants can be used in this case to increase electricity production to the level needed. The ERJ Supply Models utilise pumped storage plants and hydrogen power plants to perform this task due to their rapid response time.

The installed capacity of hydrogen power plants utilised in all the ERJ Supply Models is 3,000 MW. As the simulation showed, this power is sufficient to support the pump storage plants in all critical conditions that might occur in the course of the year 1999; this is the year that was simulated. The simulation included the introduction of summertime, which was helpful in minimising the installation capacities of Fast Reacting Power Plants (see the chapter „Simulating the Dynamics of ERJ“ on page 91 for details).

5.3) Installed Technologies in Scenario One of the ERJ Supply Model

The ERJ Supply Models utilise photovoltaic panels, hydropower, wind power and geothermal sources for the direct production of electricity. Surpluses in the electrical supply system are converted into hydrogen that can be used as a fuel for different types of plants (cogeneration, power plants for electricity generation and furnaces for producing heat). Solar power plants are not considered in the Scenario One, but are considered as an option for an additional production of hydrogen (see section on scenarios for further information).

Regarding heat supply solar collectors are the only technology that is used for direct heat production from renewable sources. Cogeneration plants and furnaces, which need fuels for operation, are used to support the solar heat supply. All heat suppliers are combined in district heating networks with short- to long-term heat storage.

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72. German Aerospace Centre (DLR) operates a solar testing facility in south Spain – the so-called Plataforma Solar de Almeria -, for hot testing both concepts and further development of solar themal power plant technology.

Fuels in the ERJ Supply Models are always calculated as the heating value of hydrogen, because, as we can now say, this will be the leading fuel in a future sustainable energy supply system. Bio fuels can also be derived from biomass. But there are uncertainties about the amount of domestic biomass that could be produced under the restrictions that have to be made to maintain the rules of sustainability. For this reason the use of biomass was not considered in this study. Nevertheless one has to be aware that biomass will contribute to energy supply.

The following Table 17, "Overview of the electrical supply in Scenario One" provides an overview of the supply of electricity in Scenario One.

Technology	**Installed capacity in MW**	**% of capacity**	**Elec. Production in GWh**	**Elec. Production in PJ**	**% of production**
PV	60,750	28.4%	82,167	296	11.5%
Total area installed: 405 km^2					
Specific area installed: 3.2 m^2/cap.					
Wind energy	56,917	26.6%	16,4361	592	23.1%
Number of plants onshore: 21,933					
Power onshore: 43,725 MW					
Number of plants offshore: 5,096					
Power offshore: 13,192 MW					
Hydropower	23,694	11.1%	125,611	452	17.6%
Geothermal energy	25,381	11.8%	180,500	650	25.3%
Cogeneration in industry	14,150	6.6%	121,306	437	17.0%
Power, steam turbines: 13,080 MW					
Power, motors: 1,070 MW					
Cogeneration in commercial and residential sector	10,890	5.1%	38,694	139	5.4%
Pumped storage power plants*	19,408	9.1%	-1,853	-7	-0.3%
Storage capacity: 1.2 PJ					
Fast reacting hydrogen power plants	3,000	1.4%	1,278	5	0.2%
Total	214,189	100.0%	712,064	2,563	100.0%

* Electricity demand for storage charge: 5,910 GWh, electrical output: 4,057 GWh

By comparison the installation data for 1999: PV 205 MW, Wind power 83 MW, Hydropower (including pump storage) 45,860 MW, Geothermal power 547 (in 2000), Cogeneration 4,973 MW, Nuclear 45,248 MW, Thermal power plants 161,869 MW. Source: Handbook of Energy & Economic Statistics in Japan, The Energy Conservation Centre, Japan; 2001.

Source: ERJ.

Table 17 : Overview of the electrical supply in Scenario One

Table 17, "Overview of the electrical supply in Scenario One" shows geothermal energy and wind power as the largest producers in the electrical supply system. Second and third positions are taken by hydropower and industrial cogeneration, which are at comparable levels. Although photovoltaic systems are in first position in terms of the installed capacity, the contribution to electrical supply is only about 12%. As mentioned above, the value of the installed capacity represents the peak power under optimal conditions. Therefore most of the time the electrical output of photovoltaic systems is much lower than the peak power.

The combination of renewable energy technologies used in the Scenario One can produce all the required electricity according to the ERJ Demand Model. The perceived shortcomings of some renewable sources, in terms of fluctuating energy production of solar and wind energy can be fully compensated by a well-chosen mixture of renewable energy technologies and an intelligent control and exchange structure. Security of supply, often unjustly cited by critics, is as reliable as with any conventional system. Please refer to the chapter on the simulation for time-dependent results.

The electrical production from domestic renewable sources amounts to about 1,983 PJ if fuel-consuming plants are not included. This is a share of about 94% compared to the electrical demand of approximately 2,100 PJ. Taking fuel-consuming plants into account, the electrical production of Scenario One is 2,559 PJ (about 122% of demand).

Technology	**Installed capacity in MW**	**% of capacity**	**Production in GWh**	**Production in PJ**	**% of production**
Solar collectors	338,745	76.9%	497,056	1,789	40.9%
Total area installed: 806 km^2					
549 km^2 in commercial and residential					
257 km^2 in industry					
Cogeneration in industry:	23,583	5.4%	202,178	728	16.6%
Steam turbines: 21,800 MW					
Motors: 1,783 MW					
Heating plants (high temp. Heat)*	60,148	13.7%	451,111	1,624	37.1%
Cogeneration in commercial and residential sector	18,150	4.1%	64,489	232	5.3%
Total	440,626	100.0%	1,214,834	4,373	100.0%

* calculated with 7,500 h/a (full load hours per year)

Source: ERJ.

Table 18 : Overview of the heat supply in Scenario One

The two main providers of heat are solar-thermal systems and heating plants. Solar-thermal systems lead by far regarding installed capacities, but this value only represents the peak power under optimal conditions, which is comparable to photovoltaic systems. Cogeneration systems produce about a fifth of the heat produced.

Regarding total installed capacities for the different regions, Kanto, Kansai and Chubu produce the greatest amount. This is because they are the most populated regions in Japan. About 64% of Japan’s population is concentrated in these regions; 36% of the population live in Kanto alone. The least amount of thermal power is installed in Hokkaido, which is the least populated region in Japan. Concerning the importance of technologies in heat production solar-thermal systems lead by far, followed by industrial cogeneration with steam turbines and cogeneration in the residential and commercial sectors.

The combination of solar collectors and cogeneration plants utilised in the ERJ Supply Model can cover the demand for low temperature heat in the industrial sector as well as in the commercial and residential sectors. The gross heat production of solar-thermal systems in the commercial and residential sectors is about 1,450 PJ, which slightly exceeds heat demand (103% of heat demand). This is not sufficient to fulfil heat demand due to the losses that occur in storage and transport of heat. Another 232 PJ of heat is therefore produced using small cogeneration systems. The resulting total heat production amounts to 1,680 PJ, which is 119% of the heat demand. The share of solar produced low temperature heat in the industrial sector is about 92% (production: 342 PJ, demand: 372 PJ).

About 30% (673 PJ) of industrial demand for high temperature heat (2,419 PJ) can be produced by the utilisation of steam turbines in industrial cogeneration. The remaining 1,746 PJ of high temperature heat has to be covered by fuels from renewable sources, whether imported or from domestic sources.

Technology	**Fuel demand in PJ**
Cogeneration	1,920
Heating plants (high temp. heat, eta =0,88)	1,984
Transport	1,176
Hydrogen from electrical supply	-371
Total	4,709

Source: ERJ.

Table 19 : Overview of fuel demand and production

Fuels are needed in Scenario One for operating cogeneration plants in the industrial, commercial and residential sectors and for vehicles in transport. The fuel consumption resulting from heat and electricity production of cogeneration plants is 1,920 PJ. Of this about 370 PJ of hydrogen is produced by the supply system itself, leaving a demand of 1,550 PJ to be supplied from other sources. In addition, about 1,980 PJ is required for the production of high temperature heat in the industrial sector and 1,180 PJ is needed for transport.

Altogether, about 4,700 PJ of hydrogen equivalent fuel remains to be found from other regional or external sources. This is not necessarily the amount that has to be imported, as additional hydrogen can be produced by the increased use of domestic renewable sources, such as wind power, photovoltaic systems or solar power plants.

5.4) The ERJ Supply Model Scenarios

Japan is a heavily industrialised, highly populated and also relatively small island. The ERJ Demand Model reduced the energy demand by about 50%, Scenario One then provided an electricity and heat supplying system covering over 50% of Japan's needs from regional sources<73>. The amount of energy that had to be covered by imports of hydrogen or biomass in this scenario amounted to about 4,700 PJ of energy. A number of scenarios (reported later in this chapter) were then developed in order to consider reducing the import percentage, ranging from increasing the amount of renewable sources, whilst still including imports, raising the efficiency levels of renewables, up to measures to reduce demand and supply in order to achieve a 100% regional supply with no imports. An overview of the scenarios can be seen in Figure 31, and detailed figures appendix.

Three scenarios (Two, Four and Six) show the effect of a decrease in the Japanese population from 127 million in 1999 to 100 million in 2050. It must be noted that a linear interpolation of demand reduction is adopted for the sake of simplicity. A demographic shift would entail an older population with smaller households and a reduced workforce, among other things. The effect would mean per capita reductions in some areas, but increases in others, making prediction extremely complex. There is also no precedent in history with which to compare the effects of such a shift.

It should be noted that although 4,700 PJ of energy imported in Scenario One is a huge amount of energy compared with the ERJ Demand, it is significantly lower than the total Japanese primary energy supplied in 1999 (about 20% of the supply in 1999). This stood at 22,971 PJ, mostly from fossil fuels or nuclear power, 80% of which was imported in the form of oil, coal and gas. Consider this in terms of oil imports: The amount of oil imported in 1999 is enormous compared to the 4,700 PJ that needs to be produced or imported in the ERJ Model. This amounted to nearly 12,000 PJ, or over 50% of Japan's primary energy supply in 1999, nearly three times the amount of energy that the ERJ Model needs to import or produce from other domestic sources in Scenario One. The table below shows the amount of energy supplied in Japan in 1999 in its various forms, expressed in Petajoules, 80% of which was imported.

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73. The fuel for transport issue is assessed in the discussion of hydrogen imports.

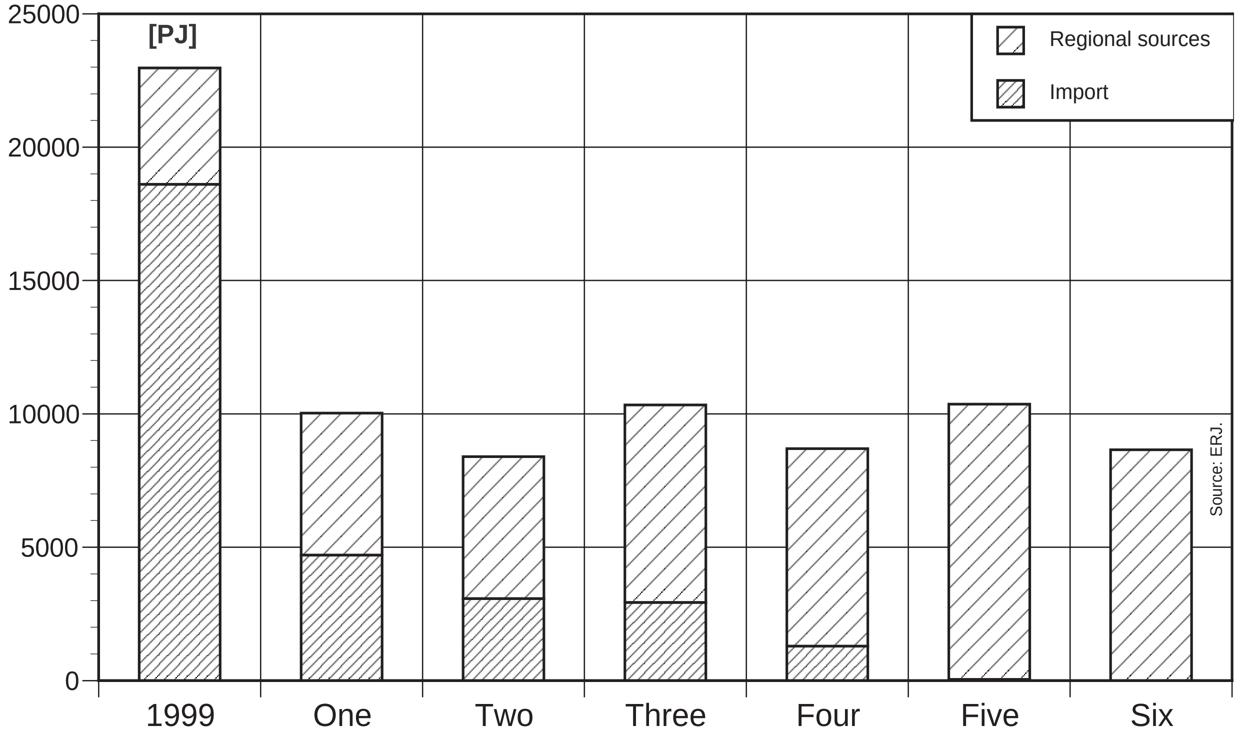

Figure 31 : Overview of the ERJ Scenarios showing primary energy supply and the share of domestic production

Energy source	**Coal**	**Oil**	**Gas**	**Hydro**	**Nuclear**	**New energy**	**Primary energy supply**
Energy in PJ	3,991	11,942	2,920	832	2,983	303	22,971

Source: EDMC (2001).

Table 20 : Primary energy supply to Japan in 1999<74>

As already stated, the 4,700 PJ of energy will be covered by hydrogen or biofuels. We therefore investigated a number of scenarios in order to consider the possible options, ranging from importing all the hydrogen to complete production in Japan. The Scenarios range from a 47% import share in Scenario One, to no imports in Scenarios Five and Six.

Sources of hydrogen from domestic renewables primarily include wind and solar photovoltaic, and geothermal sources. The ERJ Research Team excluded increased large-scale hydropower provision in Japan due to the environmental impact of such plants, although clearly there is much scope for small-scale hydropower, including along rivers. Such small-scale hydropower is viable, but more research is required into the potential for Japan. Sustainably produced biomass also

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74. EDMC (1999).

holds enormous potential for substituting a part of the import share, but the amount available was unknown at the time of publication of this study. Other renewable sources such as tidal power were not considered due to the level of development and their as yet unknown potential.

5.4.1) Increasing the Share of Renewables – What is possible?

Solar Photovoltaic

The ERJ Scenario One includes approximately 405km^2 (about 46% of the area mentioned above) of photovoltaic generators. This is equivalent to an average surface area of 3.2m^2 per capita. If the suitable area in the commercial and industrial sectors is also considered, 31% of the total available area in Japan was used for the installation of photovoltaic systems in Scenario One<75>. This is increased to 4.8 m^2 per capita in Scenarios Three, Four and Six, and further increased to a maximum of 6.0 m^2 per capita in Scenario Five, representing about 60% of the total available area<76> in Japan.

Increasing the efficiency of solar cells offers additional potential. The PV systems used in Scenario One are 15% efficient. The other scenarios use efficiency values of up to 18% (BP Solar currently produce mono-crystalline cells with an efficiency of 18%). The maximum efficiency reached in the laboratory is 24.7% for silicon-based mono-crystalline solar cells of the wafer type. Past experience shows that the maximum efficiency reached in the laboratory will be found within the commercial arena after approximately ten years<77>. A further development of the Institute for Solar Energy Research (Institute für Solarenergieforschung, ISFH) in Hameln, Germany is the MINP solar cell, with which a standard solar cell - with p-n junction - having an MSI contact, was combined with a structured surface; the efficiency reached was 21.1%. According to ISFH this technology offers the potential for economical mass production.

Solar-thermal

Solar-thermal systems are used in the industrial and commercial sectors to support other heat producing technologies. In these sectors ten percent of the suitable areas (approximately 1,714 km^2 in the commercial and approxmiately 2,569 km^2 in the industrial sector) were used for installa-

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75. This is equivalent to about ten percent of the commercial and industrial sectors, 170 km^2 in the commercial and 260 km^2 in the industrial sectors.
76. The total available area is described in the section on energy sources. This area is located on roofs and façades with a southerly orientation.
77. Green, M. (2001)

tion, which is a quite conservative approach, especially with regard to flat roofs, which are in the majority in the industrial and commercial sectors.

The total area of solar-thermal collectors in all ERJ Supply Models is about 800 km^2, thereof approximately 280 km^2 on top of residential buildings (about 30% of the suitable area), about 170 km^2 on commercial buildings, and roughly 260 km^2 on industrial areas; this is about ten percent of the available area in the commercial (approximately 1,700 km^2) and industrial (approximately 2,600 km^2) sectors.

Hydropower

The use of hydropower is not increased in any of the scenarios beyond that used in Scenario One. This amount is ten percent greater than presently supplied in Japan, the increase resulting from the modernisation of plants as described in the section on energy sources.

Wind

In total, 27,029 wind turbines are installed in Scenario One, with 5,096 plants offshore and 21,933 onshore. The total electric power is 56,917 MW, which is less than five times greater than was installed in Germany by the end March 2003<78>.

To get an impression of Japan’s wind power potential compared to Germany's, the length of Japan’s coastline is about 29,000 km, whereas the German coastline is approximately 1,000 km. The potential in Germany has been estimated at about 65,700 MW peak power<79>. This includes sites up to 30km distance from the coast and up to a water depth of 40m. They even mention the possibility of supplying the total electrical demand by offshore wind energy from the North Sea. This requires an installed capacity of about 136 GW. The area required would be 107 km^2. Thirty projects are planned in Germany with a total of 60,000 MW peak power at the request of the Bundesamt für Seeschifffahrt und Hydrographie (BSH) in Hamburg<80>. DEWI forecast an installed capacity of 15GW to 26 GW in 2030.

If Germany is able to produce so much energy from offshore wind parks with such little coastline (around 1000 km), Japan should have no problem with its 29,000 km of coastline.

The world’s largest offshore windpark, with a capacity of 160 MW has now been completed at Horns Rev in Denmark. The windpark, consisting of 80 turbines oftwo MW, is capable of produc-

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78. Bundesverband Windenergie e.V. (2002).
79. DEWI (2001), Ender, C. (2002), Molly 2001, Rehfeld 2002.
80. Bundesverband Windenergie e.V.(2002).

ing 160 MW in full operation, and is expected to produce approximately 600 million kWh (600 GWh) annually, roughly two percent of the total power consumption in Denmark. The Danish plan is to provide a total capacity of 4,000 MW in Danish waters before 2030.

Photo copyright: Elsam A/S.

Figure 32 : Horns Rev in Denmark

It is difficult to quantify the maximum potential for wind power in Japan. Taking into account the installation density in Scenario One, the upper limit is set to 0.5 plants per km^2 onshore, and 0.15 per km^2 offshore. The highest density onshore is in Kyushu South with 0.39 per km^2, and offshore it is 0.106 per km^2 in Hokkaido West. Taking these values and the average size of wind parks at 25 units per wind park, a distance of over 11km between windparks is seen at Kyushu South. Offshore installation distances range from 7km to 70 km. Tripling onshore installation is therefore not a problem regarding area or wind. The only limitation with offshore plants is in Hokkaido West, which is already well used.

The world potential offered by wind energy is immense. Its potential even exceeds the estimated world electricity demand in 2020 by more than a factor of two. The Greenpeace study “Wind Force 12” showed that 12% of the world’s electricity demand could be covered by wind energy by the year 2020<81>.

Geothermal

The potential for geothermal energy in Japan is not as great as with wind. According to the Institute for Energy and Total Engineering<82>, Japan’s geothermal sources located outside of national parks offer the potential for installing power plants with 76,158 MW of electrical power. Scenario One uses just over 22,900 MW of geothermal power plants (about 25% of the potential) for the

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81. EWEA (2002).
82. NEDO (1989).

production of electricity. So clearly there is scope for an increase of 75% in theory. Scenarios Three, Four and Six increase the use of geothermal to 35% of the potential and Scenario Five uses 40%. In addition, the degree of utilisation in Scenario One is equivalent to approximately 7,000 full load hours a year. Scenarios Three to Six increase this to 8,100 full load hours.

Further improvements can be achieved by using the Organic Rankin Cycle technology. This technology is already well established<83>. In addition, further improvements can be made through the “Kalina cycle” produced by General Electric & Exergy, which claims it is possible to increase the efficiency of geothermal power production by 50%, using this system<84>. Those plants can reach an overall efficiency of up to 62% according to the manufacturers.

Figure 33 : An ORC power plant<85>; Source :Turboden, Brescia, Italy.

Solar-thermal Plants

Scenarios Five and Six utilise solar-thermal plants for the production of hydrogen. These must be located in southerly areas in Japan and require, 600 km^2 and 410 km^2 respectively. Clearly the

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83. Turboden s.r.l., in Brescia, Italy market an ORC plant with a electrical efficiency of 18 %.
84. California Energy Commission (1997).
85. Two geothermal power-plants using the ORC (Organic Rankine Cycle) technology are already in operation in Austria and Germany. The plant in Altheim, Austria from Turboden has a generating capacity of 1.000 kW. After a testing period of two years the plant is in normal operation since September 2002. The German plant in Neustadt-Glewe started operation in November 2003 and has a generating capacity of 210 kW. Sources: [Geothermische Energie 36/37 - Sonderheft Altheim, 10. Jahrgang/Heft 3/4, Juni/September 2002, Magazin of Geothermische Vereinigung e.V., Germany; 2002], [Erdwärme-Kraft GbR, Berlin, Germany; 2003].

maximum potential is restricted to the amount of free area available in the south of Japan. The most southerly islands of Okinawa for example cover 2,267 km^2 .

5.4.2) The Scenarios

Scenario One: Importing Energy in the Form of Hydrogen

As already stated, Japan does not have much available space, so future development will show if a greater proportion of the hydrogen required gets imported from areas where space, costs and radiation conditions are more ideal for hydrogen production. Issues of hydrogen in a future energy system are discussed later in this report. Please refer to table in appendix for detailed information regarding the scenarios.

Scenario Two: Population Change

This is the same as in Scenario One, but the projected decline in the Japanese population from 127 million in 1999 to 100 million by 2050 results in a reduction in energy demand from nearly 7,500 PJ to under 6,000 PJ. The supplies of electricity and heat remain the same, but the supply of fuels from electrical surpluses almost doubles, coupled with a decline in consumption of fuels for heat production. This results in a surplus of fuels and a resulting increase in supply to cover 63% supply of Japan’s energy needs with 3,075 PJ of hydrogen to be imported. This is now 13.4% of the import share compared to 1999.

Scenario Three: Offshore Offensive

Energy supply is increased, mostly using offshore wind power, as the name suggests. A number of measures are taken to increase energy supply from domestic sources including:

Photovoltaic: (PV) installation was increased by a factor of 1.5 compared to Scenario One, reaching 4.8m^2 per capita. PV’s efficiency was also increased to 18% (compared to 15% in Scenario One). This, coupled with heat supply in industry is still less than the total surface area available in Japan.

Heat supply in industry: The amount of solar collectors in industry was doubled (an additional 257 km^2).

The amount of area required for photovoltaic and solar collectors is still less than the maximum area available in Japan<86>.

Wind: The onshore installation of windmills remained unchanged, while the offshore installation is four times the amount of plants, compared to Scenario One. It was assumed that all additionally installed windmills are five MW plants. So the average installed power climbs from 2.6 MW in Scenario One to 4.4 MW in Scenario Two.

Geothermal: The used potential was set to 35% and the amount of full-load hours increased to 8,100 hours per year. Organic Rankin Cycle technology (ORC) is used in all geothermal plants. Efficiency is still 17.7%.

Use of electrical surpluses: The efficiency of hydrogen production was set to 80%.

These measures raise the amount of energy produced from regional sources from 5,321 PJ in Scenario One to 7,403 PJ or 72% of Japan's energy needs. Another 2,932 PJ must then be supplied by imported hydrogen or regionally produced sources. This is under 13% of the 1999 import share.

Photo copyright: Elsam A/S.

Figure 34 : Horns Rev in Denmark

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86. Please refer to the discussion on maximum installation in Japan for estimates of the maximum installation capacities (section 5.2.1).

Scenario Four: Offshore Offensive combined with Population Reduction

Measures are the same as with Scenario Three with increased energy supply, but the population decline described in Scenario Two is adopted, resulting in an increase in the share of domestic energy supply to 85% and a reduction in imports to 1,294 PJ or 5.6 % of the 1999 import figure.

Scenario Five: Full Supply and Rational Use of Electricity

Electricity not needed to cover the fuel demand of cogeneration and transport is used for heat production, rather than converting surplus electricity to fuels and then heat. A direct conversion to heat is 90% efficient compared to conversion to fuels first and then combustion (with an efficiency of 75% See the discussion on electrical surpluses below). Further measures taken to increase energy supply from domestic sources include:

Photovoltaic: (PV) The area was increased to 6m^2 per capita, with efficiency remaining at 18% An additional 6m^2 per capita was installed on façades of buildings.

Heat Supply in industry: The amount of solar collectors for industrial process heat was tripled (an additional 514 km^2).

Solar-thermal plants: This scenario utilises 600 km^2 of solar-thermal power plants (with an efficiency of 20%).

Wind: Efficiency was assumed to be 30% instead of 25% in Scenario One.

Onshore installation (installed units) was increased by a factor of 2.5. Offshore installation (installed units) was increased by a factor of 4.5. All offshore plants are of the 5MW type.

Geothermal: Increased use of geothermal potential to 40%. ORC is used in all plants with an efficiency increased to 20%.

Use of electrical surpluses: The efficiency of hydrogen production was increased to 85%. Only a part of electrical surpluses is used for fuel production (after fuel demand of cogeneration and transport is covered). The remaining electrical surplus is used for direct production of process heat in industry (efficiency 90%) This reduces the need for heating plants. The conversion chain of electricity to heat is more effective (an efficiency of 90%) than the chain of electricity to fuel and then to heat (an efficiency of 75%).

This scenario provides over 10,000 PJ from domestic sources, equivalent to almost 100% of Japan’s needs.

Scenario Six: Full Supply, Rational Use of Electricity and Population Change

Again the projected population decline is employed and combined with Scenario Five. The main differences include:

Photovoltaic: Area: 4.8m^2 per capita (1.5 times of Scenario One, but less than in Scenario Five). No façade mounted PV is included.

Heat supply in industry: The amount of solar collectors in industry was halved compared to Scenario Five.

Solar-thermal plants: Area of 410 km^2.

Wind: The number of onshore windmills is a third greater than in Scenario One, but much less than in Scenario Five. Offshore is just under four times the amount of Scenario One (slightly less than in Scenario Five), using only 5MW plants (this differs from Scenario 3). Efficiency remains at 30%.

Geothermal: Used potential is 35%, with all plants using ORC. Full-load hours: 8,100 hours per year.

Use of electrical surpluses: The efficiency of hydrogen production was set to 85%. Only a part of electrical surpluses gets used for fuel production (fuel demand of cogeneration and transport are covered). The remaining electrical surplus is used for direct production of process heat in industry (efficiency 90%) This reduces the need for heating plants as explained in Scenario Five.

This is a 100% regional supply, producing over 8,500 PJ of energy, with no imported fuels.

5.4.3) Which Scenario offers the Best Solution?

All of the above scenarios are feasible in Japan, both in technical terms and in terms of natural resources, such as wind, solar radiation and geothermal capacity. The decisive factors will be costs, public acceptance and priorities set by national policy in terms of energy security and international commitments. In terms of costs and energy security, a mixture of regional sources including sustainably produced biomass, supplemented by imports of hydrogen represents the best solution to ensure a sustainable supply.

These scenarios provide a number of possible solutions, but these are in no way comprehensive as many variations are possible. The team have attempted to offer a wide spectrum of possibilities, but do not attempt to provide an “ideal” solution.

5.4.4) Domestic Energy Production in the ERJ Scenarios

In Scenario One, the electrical output of photovoltaics, wind power, hydropower and geothermal energy is equivalent to 48% of the total energy production. Solar-thermal collectors produce an additional 14%. Renewable fuels account for about 38% of energy production; this consists of the three percent of energy that is produced by domestic hydrogen production. These results do not consider opportunities of increasing the domestic share of energy production, such as sustainably produced biomass and an extended use of renewable sources for hydrogen production. Scenario One shows that at least 53% of energy can be produced from domestic renewable sources. A number of alternative scenarios for covering the remaining demand are also presented.

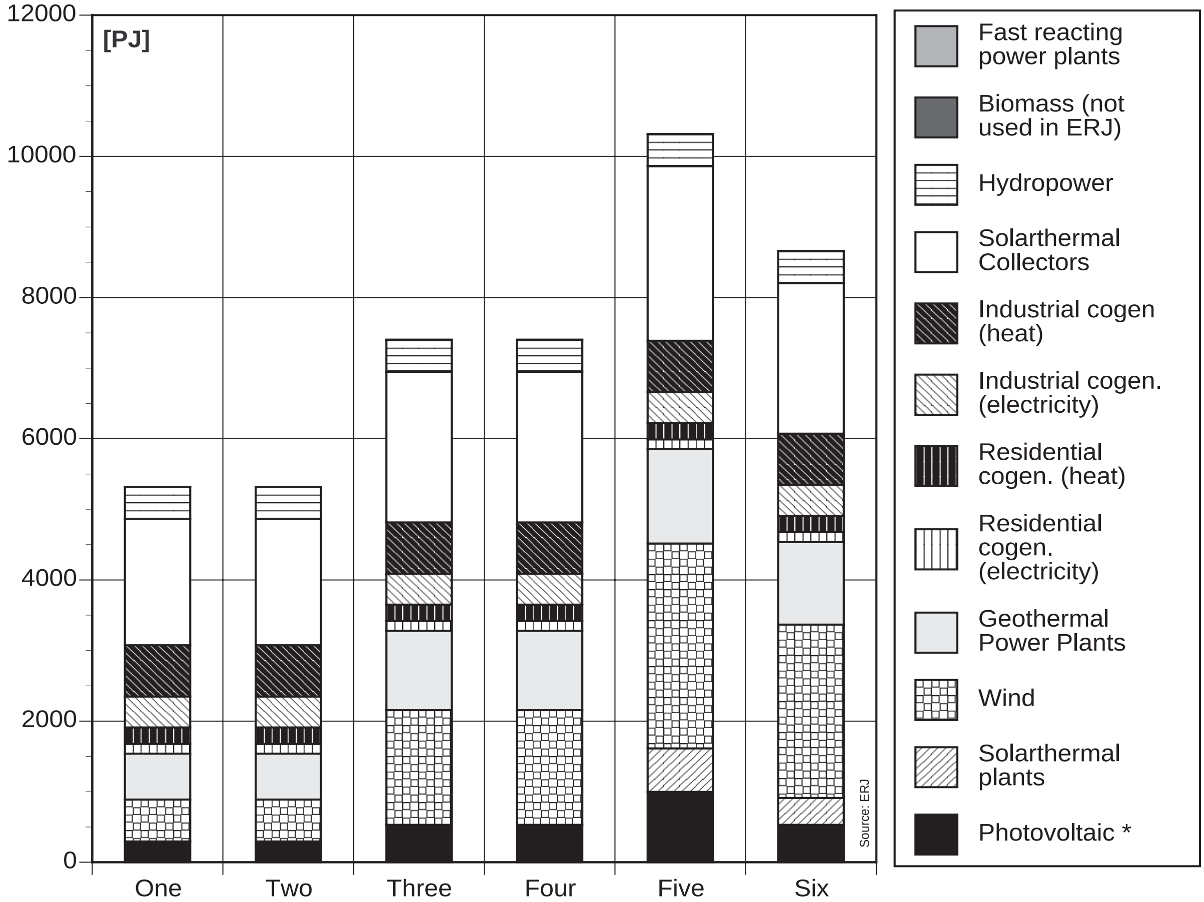

Figure 35 : Domestic energy production in all “Energy-Rich Japan” scenarios. This is the production of electricity and heat in the installed power plants. Biomass is set to zero. Sustainably produced biomass holds enormous potential, but the amount available was unknown at the time of publication of this study

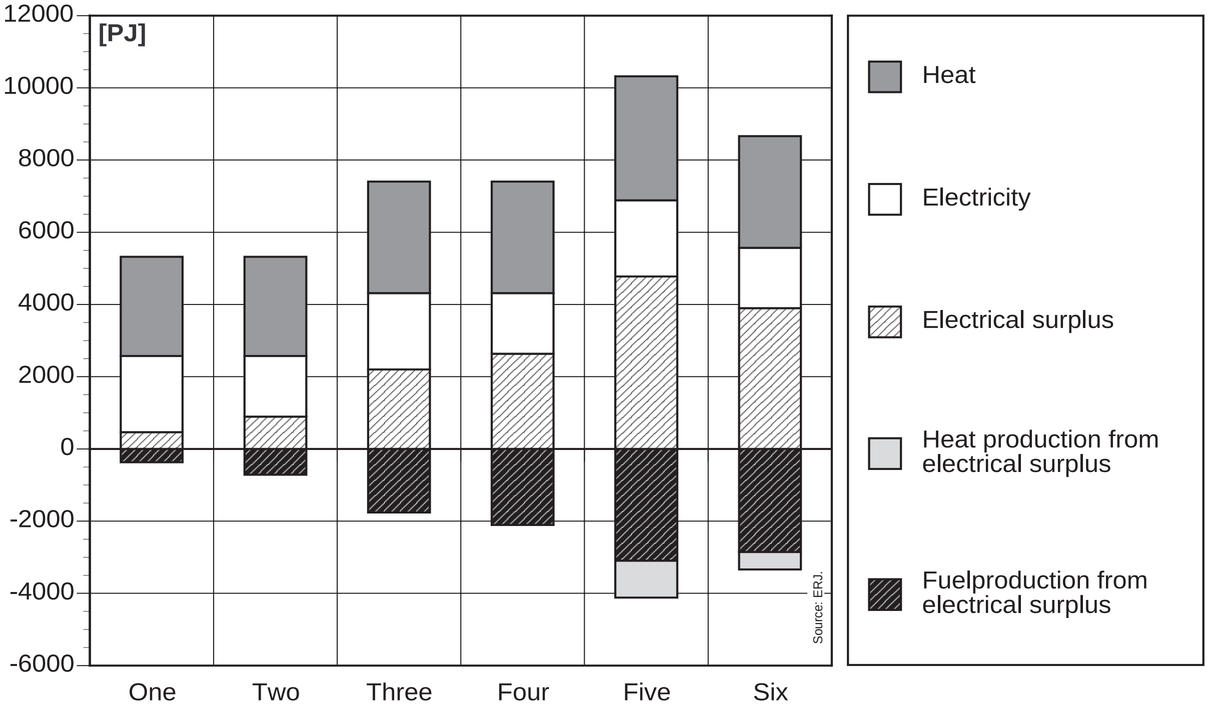

Figure 36 : Domestic electricity and heat production in all six "Energy-Rich Japan" scenarios. Electricity surplus is used for heat and fuel production

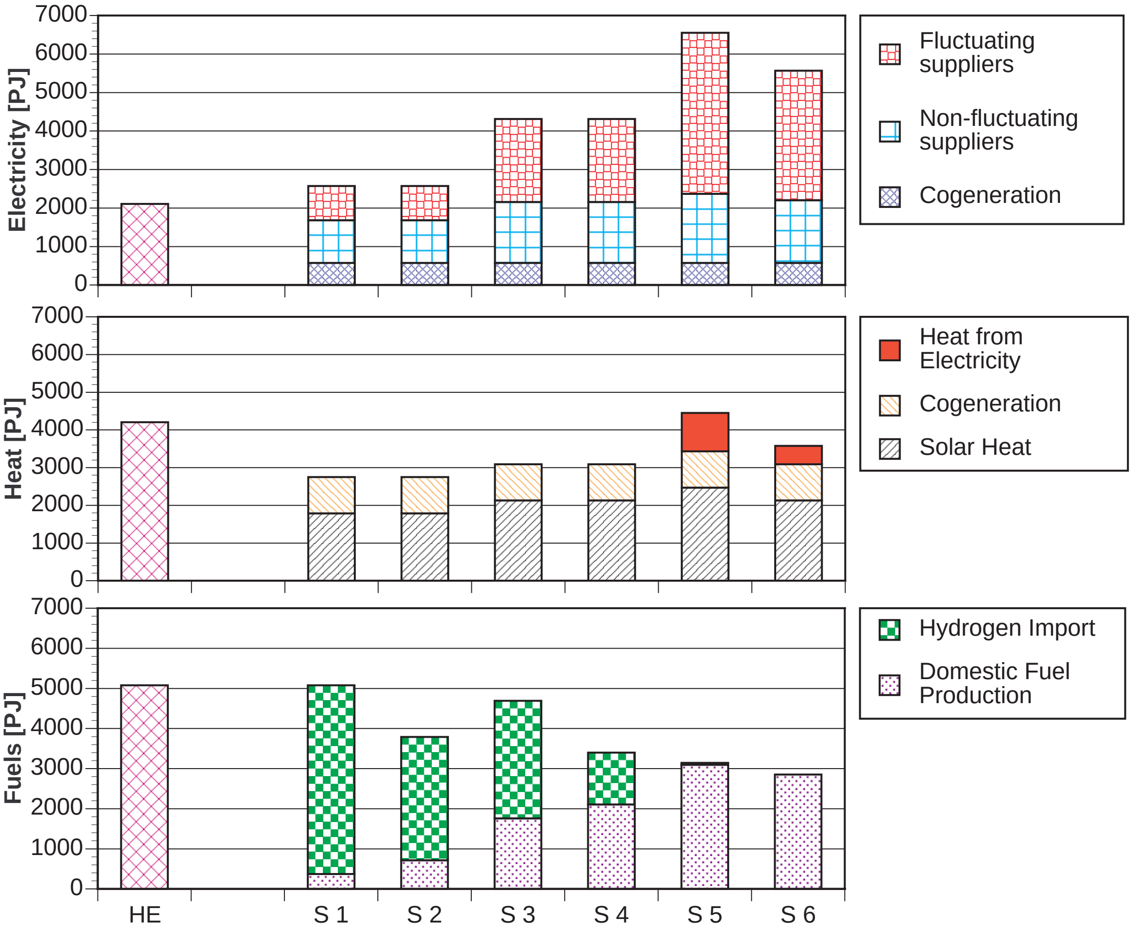

Figure 37 : Electricity, heat and fuel production in all six "Energy-Rich Japan" scenarios. Electricity surplus is used for heat and fuel production

5.4.5) The Use of Hydrogen in a Future Energy System

Importing hydrogen represents no technical barrier in terms of production, the amount that can be produced, the technology or transport, whether by ship or by pipeline<87>. The global potential exists for solar-thermal plants worldwide, mostly in desert areas, to sustainably produce 344x103 PJ of hydrogen per year<88>. The amount required by Japan is only 1.3% of this figure. By comparison, the worldwide primary energy consumption in 1999 was 360x103 PJ. In other words the world's total primary energy consumption is only a little more than could be produced a from solar-thermal plants producing hydrogen. The world wind potential is also enormous with an ability to produce 153x103 PJ of hydrogen.

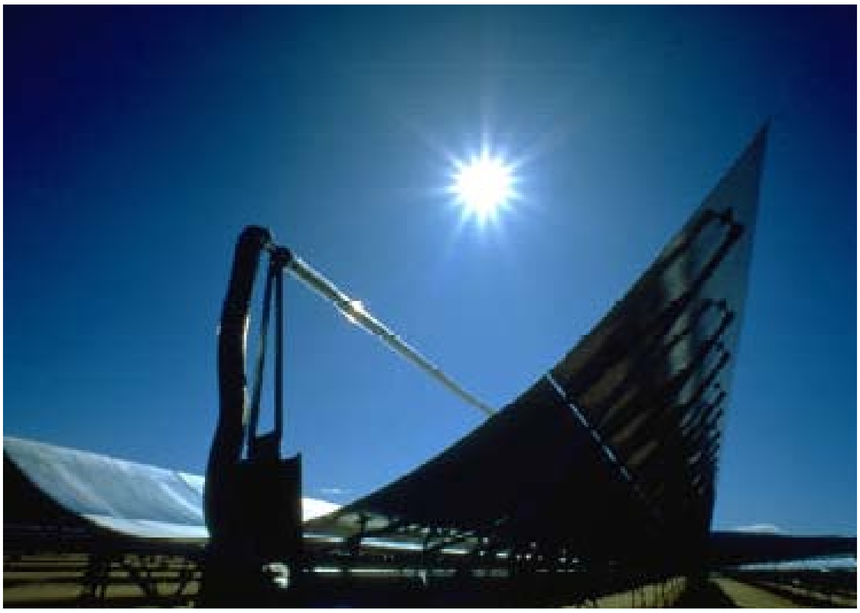

Photo copyright: Duke Solar Energy, Raleigh, USA.

Figure 38 : Parabolic reflectors producing electricity used for hydrogen production

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87. This issue is discussed in detail in the Greenpeace commissioned report: "Hydrogen Production via Electrolysis using Electricity from Renewable Energy Sources in Off-grid Regions" by the Frauenhofer Institute in Germany.
88. DLR (1989).

	Electrical potential (TWh)	**Hydrogen production ($x10^3$ PJ)**	**Japan's $4.5x10^3$ PJ as % of total**
Global wind power potential	53,000	153	2.9
Solar-thermal plants in desert regions and wastelands (1.9 million km^2)	119,430	344	1.3

Note: assumed electrolyis efficiency of 80%<89><90>.

Source: ISUSI (2003).

Table 21 : Global hydrogen production and Japan’s demand in Scenario One

The issue of creating a hydrogen infrastructure for supplying transport and combined heat and power is a matter for policy decisions and market forces. In the transportation sector we have really only seen research and development in the last 15 years. This makes it difficult to make recommendations or predictions, but many lessons have been learnt from experiences in the last few years with the use of natural gas in vehicles.

A hydrogen infrastructure already exists in parts of the world. For example at Munich airport in Germany, a fully functioning network of hydrogen fuelling buses exists. Two extensive hydrogen networks have been in existence for over 50 years in Germany. One is located in the industrial Ruhr valley and is operated by BOC under contract for Hüls AG. The second is located in Leuna-Bitterfeld-Wolfen and is operated by Linde AG. Both networks include over 50 km of piping and connect local producers and consumers, mostly in the chemical industry.

Icelandic New Energy Ltd. is a joint venture company that was founded to investigate the potential for eventually replacing the use of fossil fuels in Iceland with hydrogen-based fuels. The planned transformation of Iceland into a hydrogen society is divided into five phases, starting with the introduction of fuel-cell driven buses in Reykjavik (2002) and ending in a fully hydrogen based energy supply by between 2030 and 2050<91>.

Another important issue is location. One central location for hydrogen production is not ideal due to transportation and security issues, but would benefit from a better price/performance ratio, as larger plants are more competitive. A distributed system of production using a range of renewable energy sources would provide for regional needs, therefore reducing transport costs. This is also a better policy for ensuring supply should one region or energy source fail.

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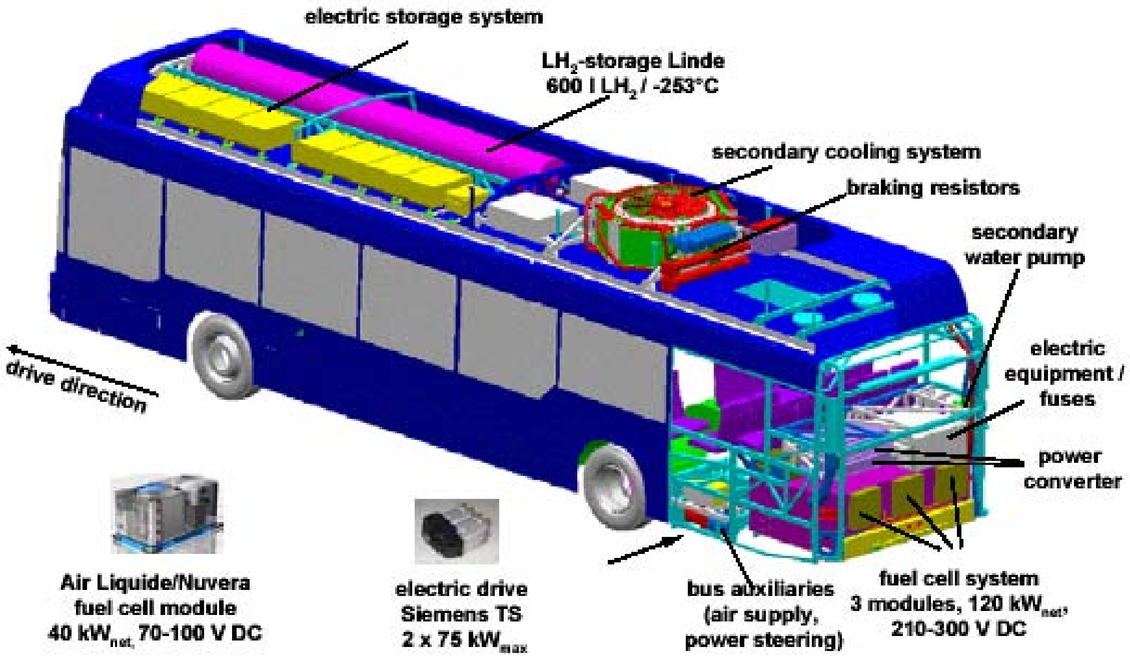
89. German LB-Systemtechnik claims an efficiency of 74-79%, related to the upper heating value of hydrogen. Energy consumption of supporting devices is already included.
90. German Fraunhofer Institut für solare Energiesysteme –ISI- has developed a PEM electrolyser with an efficiency of 85%. (Hydrogen Production via Electrolysis using Electricity from Renewable Energy Sources in Off-grid Regions; 2003).
91. The Company is owned by VistOrka hf, Daimler-Chrysler AG, Norsk Hydro ASA and Shell Hydrogen B.V. Icelandic New Energy Ltd., 2001.

Hydrogen in Transport

In May 2000 MAN presented its first city bus using an emission-free PEM-fuel-cell drive jointly developed by Siemens and Linde in Germany. The fuel-cell system, consisting of four inline connected stacks, produces 120 kW electric power for the drive system and is supplied by hydrogen from 250 bar high pressure storage tanks mounted on the bus roof<92>. The bus was successfully tested as a regular city bus service between Nuremberg, Erlangen and Fürth in Germany October 2000 and April 2001.

A number of cars and buses have been successfully running on both liquid and gaseous hydrogen since 1999 in the Munich International Airport hydrogen project<93>. Refuelling of the cars is fully automated and made safe with the use of advanced robotics, coupled with gas sensors.

On 10th of March 2003, the Japanese Ministry of Infrastructure and Transport gave General Motors the first permission for a car operated with liquid hydrogen to operate on Japanese roads to the GM/OPEL HydroGen3. It also received the first permission for an LH2-vehicle fuel tank from the Japanese High Pressure Gas Safety Institute of Japan.



Source: Karl Viktor Schaller, Christion Gruber (2001) Hydrogen Powered Fuel-Cell Buses Meet Future Transport Challenges. MAN Nutzfahrzeuge AG.

Figure 39 : Schematic diagram of the MAN hydrogen bus

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92. Nowadays pressure tanks with 350 bar pressure are state of the art, whereas tanks up to 700 bar are currently under development (Source: LB-Systemtechnik (2003)).
93. The project, run by a consortium called ARGEMUC, consists of 14 German companies along with the free state of Bavaria, which has a 50% stake in the project. Gaseous hydrogen is generated locally by electrolysis and Linde TG supplies liquid hydrogen from Ingolstadt.

On the 11th of March the first Japanese test centre for fuel cell vehicles was officially opened. In the project five car manufacturers, (DaimlerChrysler, General Motors, Honda, Nissan and Toyota) and further companies from the energy industry, have combined in order to test fuel cell vehicles and the fuel infrastructure in everyday use. The Japan Hydrogen & Fuel Cell Demonstration Project<94> (JHFC), promoted by the Japanese government in close co-operation with industry, has the goal of advancing the science and the readiness for the market of this technology. The JHFC mechanism offers long-term conditions for vehicle testing, as both workshops and an information centre are available to users. The first of five hydrogen gas stations for the fuel cell cars opened one day later in Yokohama, Japan. DaimlerChrysler is planning to lease fuel cell vehicles in Japan by the second half of 2003.

The plan is to lease up to ten vehicles in Japan between 2003 and 2004. DaimlerChrysler's Japanese partner Mitsubishi is said to support the project. DaimlerChrysler intends to deliver 60 fuel cell A-class-vehicles in Europe, the USA, and Singapore between 2003 and 2004<95>.

Briefly after distribution of the first leasing vehicles with fuel cell drive, Toyota presented a new concept vehicle at the Detroit Motor Show. According to Toyota the vehicle represents only the beginning of a whole set of planned new vehicles. The drive (fuel cell hybrid) is a basis element of a modular structure and is identical in each case and can therefore be easily integrated into further vehicles.

Hydrogen Safety Issues

Hydrogen has been used safely in vast quantities in chemical and metallurgical applications, the food industry and the space program for many years. Hydrogen and fuel cells will soon play an even greater role in meeting our energy needs. Like all fuels, hydrogen can be used safely with appropriate handling and engineering controls.

Similar to the fuels we use today, there are hazards associated with handling and using hydrogen, but industry has shown that hydrogen can be used safely in a wide variety of applications and conditions by employing proper safety controls. Safety considerations associated with handling hydrogen include fire, explosion, and asphyxiation. Hydrogen is the lightest gas known and is very buoyant, which means it quickly dissipates to the surrounding air. It does not spontaneously combust<96>. It is flammable over a wider range of concentrations than either petrol or natural gas, but it dissipates more rapidly than either of these fuels in a spill. Hydrogen gas, like other gases used today, should be used in areas that can be ventilated.

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94. JHFC (2003).
95. HyWeb (2002).
96. The ignition point of hydrogen is 570˚C, compared to petrol at 500˚C.

As with all fuels, appropriate measures can be put in place to achieve acceptable levels of safety. With proper handling and controls, hydrogen can be as safe as, or safer than, other fuels that we use today.

Hydrogen has a higher combustion energy per kilogram relative to any other fuel, meaning hydrogen is more efficient on a weight basis than fuels currently used in air or ground transportation. This weight factor makes hydrogen an attractive fuel, although the volume required for the same energy is greater.

6 Simulating the Dynamics of ERJ

The SimRen simulation was developed to study the dynamics of an energy supply system consisting solely of renewable energy sources. SimRen was used to plan and optimise the supply system for Japan. The objective of this optimisation was to assure a reliable supply at all times and to supply Japan with electricity without importing energy from outside of Japan. The simulation calculates the deliverable energy from installed power plants using time-resolved methods. The installation of power plants was adjusted until the optimal amount of installed power plants was found. (further information see Appendix)

The year 1999 was taken for the reference year of the ERJ Demand Model and therefore the time span that was simulated. A time span of a whole year had to be simulated in order to ensure that seasonal variations and critical weather situations were included and tested.

According to the Japan Meteorological Agency the year 1999 had weather conditions that are a little below the average. The average wind speed and the solar irradiation were below the average for the years 1975-2000.

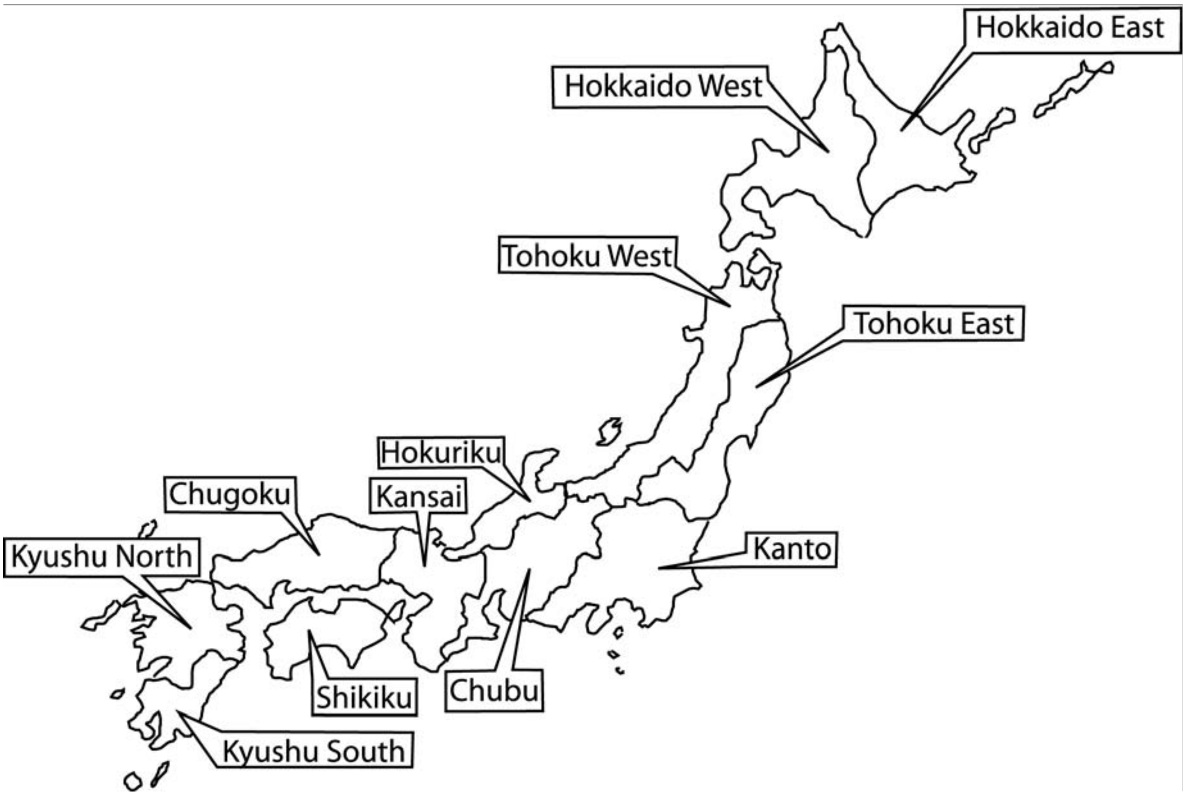
	Average 1975-2000	**Average 1999**
Wind speed	3.2 m/s	2.9 m/s
Solar irradiation	12.9 MJ/qm	12.5 MJ/qm
Temperature	13.7 ˚C	14.2˚C

Source: Japan Meteorological Agency.

Table 22 : Average wind speeds and solar radiation in Japan

A well thought-out spatial resolution was also seen as important for the significance of the results, as all weather-dependent effects had to be simulated with a high resolution to be as realistic as possible. Consequently, all available weather data was taken into consideration for the SimRen Simulation for Japan. The information from 153 weather stations uniformly distributed over the whole country was available. The potential photovoltaic production was calculated using 66 of these stations, which also measured solar radiation.

All the other data integrated into the model of Japan was available from the ten Japanese districts. Some regions were divided into two, because of differing meteorological and geographical characteristics. These were Hokkaido East and West, Tohoku East and West and Kyushu North and South. Thus the ERJ Electrical System Model has 12 regions as shown in the picture below. The energy consumption of Okinawa was only available combined with Kyushu and is therefore included in the Kyushu demand. Since most of the southerly islands cannot be integrated in the Japanese electrical grid, only the islands of Yakushima and Tanegashima were used. The more southerly islands can be used to produce hydrogen, because they have very high wind speeds and solar radiation but this was not included in the simulation. Some regions were divided into two, because of differing meteorological and geographical characteristics. These were Hokkaido East and West, Tohoku East and West and Kyushu North and South. Thus the ERJ Electrical System Model has 12 regions as shown in the figure below.



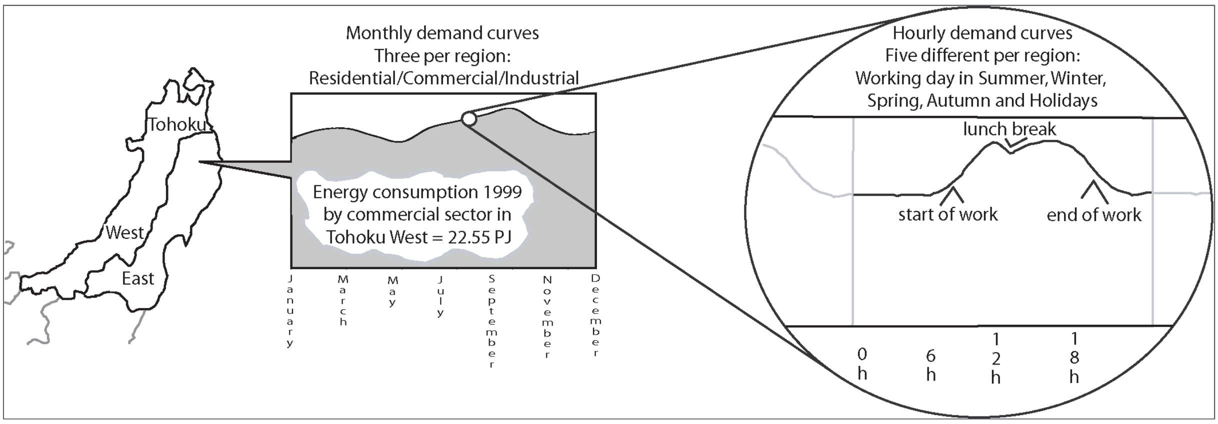
Source: ERJ.

Figure 40 : The 12 regions of the ERJ Electrical System Model

6.1) The ERJ Electrical Demand Model

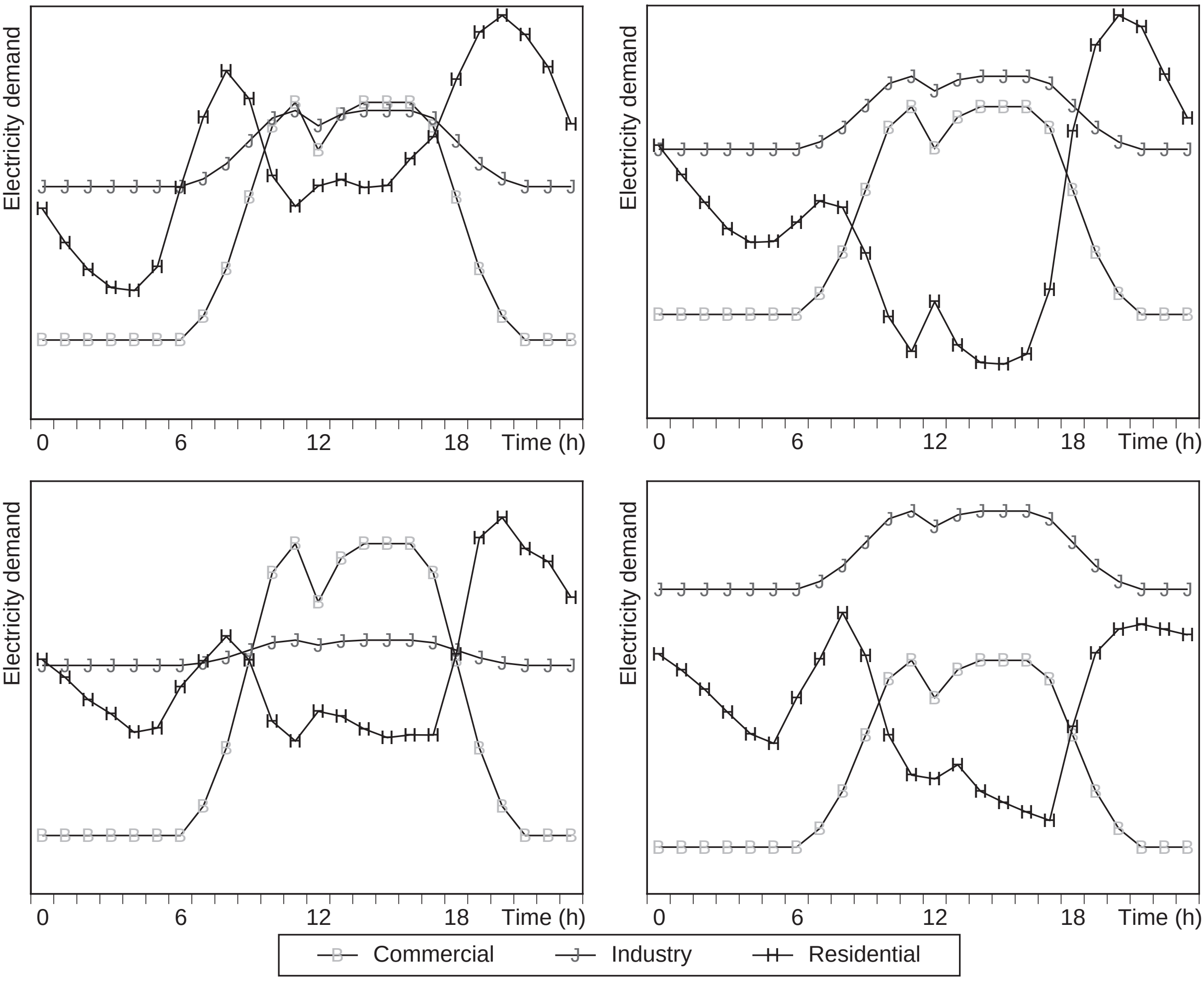
SimRen calculated the energy demand of a consumer group at a certain point in time using typical daily and yearly demand curves. The consumer groups were residential, commercial and industrial consumers. The way this was done is illustrated in the figure below.

A unique yearly demand curve was developed for each consumer sector and district in Japan, which indicated how much electrical energy was consumed in a certain month in that sector of that region. In addition, the ERJ Demand Model contained information about the amount of energy consumed in a whole year in the residential, commercial and industrial sectors.



Source: ERJ.

Figure 41 : Analysis of annual demand in Tohoku East showing daily fluctuations



Source: ERJ.

Figure 42 : Examples of hourly demand curves

A monthly resolution of the demand data was considered far too low for meaningful research. SimRen therefore used daily demand curves that were combined into a yearly curve resulting in the correct sum total for the whole year. In addition, the daily demand curves were scaled with the yearly curves as they also included monthly tendencies. For Japan, daily demand curves for spring, summer, autumn and winter, and a curve for public holidays were developed. These curves differed from region to region and demand sector to demand sector.

The final demand curve SimRen used included a random fluctuation of five percent to reproduce more realistic consumer behaviour, as consumers are not entirely predictable.

6.2) The ERJ Electrical Supply System

An intelligent regulation of the adjustable energy suppliers was vital in order to realise a good working electrical supply system. Electricity suppliers in SimRen were categorised as fluctuating or adjustable.

6.2.1) Fluctuating Energy Suppliers

Wind and photovoltaic are fluctuating energy suppliers because they depend on the wind and solar radiation respectively. In addition to these two suppliers, cogeneration plants in the residential and commercial sector were also classified as fluctuating energy suppliers as the heat needed in that sector determined the energy production. The residential and commercial consumers used combined heat and power plants to heat houses or water. Electricity production therefore depended on atmospheric temperatures in the region.

Photovotltaic

According to existing technologies, which reach an efficiency of 15%, we used this efficiency as well. After calculation of the irradiation on a declined surface having regard to the shading effects the energy output is calculated using the efficiency of 15% and the thermal change of the efficiency.

The photovoltaic areas we used for ERJ Japan had the alignment shown in the Table 23.

Solar-thermal Energy Calculation

The heat that can be produced with solar thermic areas has also been calculated with SimREN, although it has nothing to do with the electrical supply of Japan. Its calculation utilises the same formulas as the calculation of the photovoltaic electricity production. We assumed an efficiency of

50% for the solar thermic areas in the commercial and residential sector, where temperatures up to 50°C are needed, and an efficiency of 25% in the industrial sector, where mostly higher temperatures up to 150°C are needed. The distribution of the alignments of the areas is the same as for photovoltaic and is shown in the Table 23.

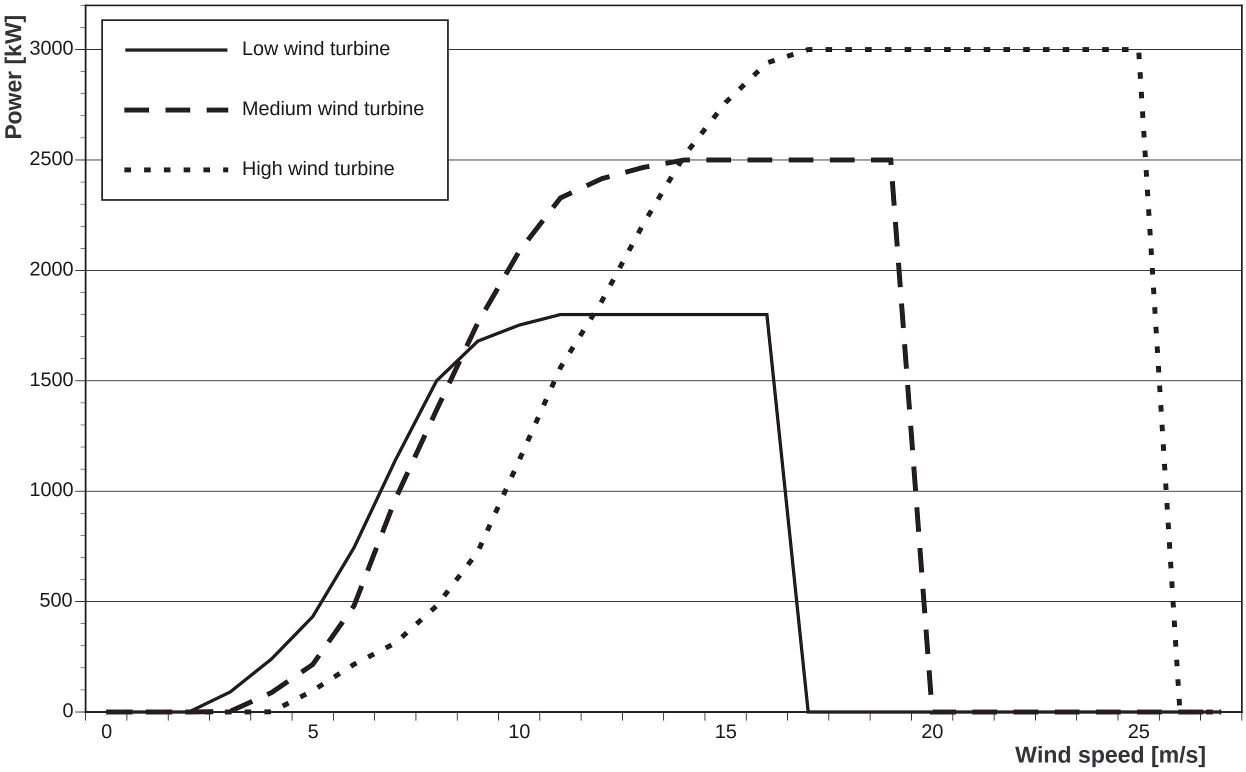
Percent of all photovoltaic areas	Inclination	Adjustment	Type of roof
50 %	Degree of latitude + 10˚	South	Flat roof Shading
25 %	Degree of latitude + 10˚	South	Sloping roof No shading
12.5 %	Degree of latitude + 10˚	South + 30˚	Sloping roof No shading
12.5 %	Degree of latitude + 10˚	South - 30˚	Sloping roof No shading

Source: ERJ.

Table 23 : Photovoltaic areas and their alingments

Wind Energy Calculation

The simulation of the energy output by wind turbines is based on typical power curves of windmills. We used three different types of windmills in SimREN, from which two are used offshore and onshore. The power curves of these types are shown in the Figure 43



Source: ERJ.

Figure 43 : Three wind turbine power curves

The two bigger windmills are used onshore and offshore. It seems that it is not profitable to install the smaller ones offshore, because of the high wind speeds offshore, the high expenses and the low energy output. The technical details of the different types are summarized below.

	Low wind turbine	**Medium wind turbine**	**High wind turbine**
Nominal output	1,800 kW	2,500 kW	3,000 kW
Height of hub	108.6 m	80 m	95 m
Cut-in wind speed	2 m/s	3 m/s	4 m/s
Cut-out wind speed	17 m/s	20 m/s	26 m/s
Nominal wind speed	11 m/s	14 m/s	17 m/s
Regulation type	Pitch	Pitch	Pitch

Source: ERJ.

Table 24 : Wind turbine technical details

The roughness used in this formula can be classified by the different kinds of landscapes. For the conversion of the wind speed in measurement height to hub height we used a roughness of 0.1. This accords to an area with bushes.

Information about offshore wind speeds was not available. Therefore it had to be calculated using the weather data from stations close to the sea. The fundamental difference between onshore and offshore is the lower roughness of the ground and consequently higher wind speeds offshore. As measurements in Denmark and Germany show the offshore wind speed is approximately 33% higher than onshore, thus we also used a 33% higher wind speed offshore than measured at the onshore weather stations. To calculate the wind speed offshore we first converted the wind speed onshore to the wind speed in hub height using the formula above, then we raised this wind speed 33% to reflect the offshore location.

Cogeneration Heating Plants Calculation

The energy production of the cogeneration heating plants in households and commercials depends on the outside temperature in the regions and the hot water demand in the households and commercial buildings. We suggest that hot water can be stored throughout the day and therefore only the production of heat for heating fluctuates. If the outside temperature falls under a predefined start temperature, the cogeneration heating plants start heating up to a target temperature. These temperatures differ between night and day. During the day the plants start heating if the temperature falls under 18°C. If this happens they heat the houses to a target temperature of 20°C. During the night the target temperature is about 15°C and the heating starts at about ten degrees centigrade, but not all rooms that are heated during the day are heated during the night. Therefore we assumed an average starting temperature of 5°C and an average target temperature of ten degrees centigrade in the whole house, to make the simulation easier. Night heating begins at 23:00h and ends at 7:00h.

The plants run at least one hour, because it makes no sense to turn them on and off every time the temperature curve crosses the start temperature. The dispensable heat is stored and can be used later.

According to existing technologies we assumed an electrical efficiency of 30% and a thermal efficiency of 50%.

6.2.2) Adjustable Energy Suppliers

Adjustable energy suppliers used in SimRen included hydropower plants, geothermal power plants, fast reacting power plants and cogeneration power plants for high and low temperature heat. The power output of the pumped storage plants was also adjustable but depended on the fill level. Although the maximum power output of the hydropower plants fluctuated with the water level of the rivers, at least the power output was controllable up to that level.

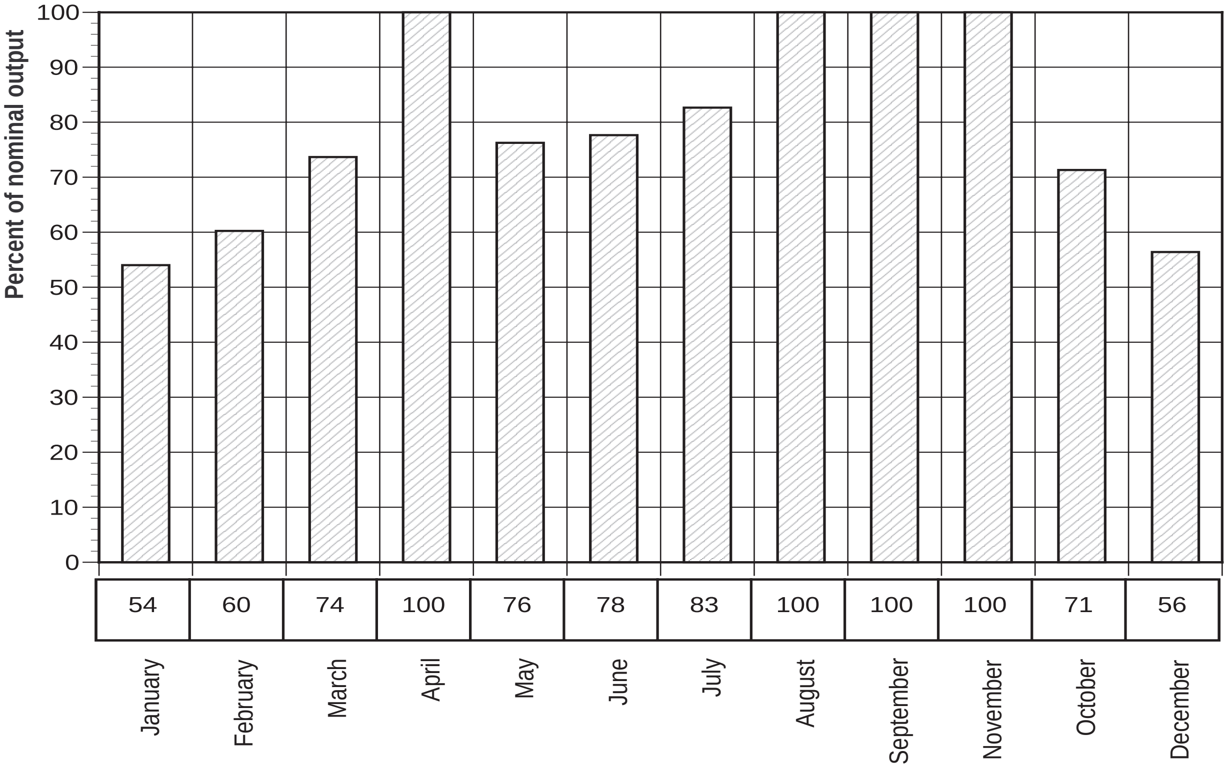
Cogeneration Heating Plants in Industry

As cogeneration heating plants have a predefined maximum power output that has been described in the ERJ supply part, their power output can be adjusted up to this output without restrictions. This applies for low temperature heat produced by motors just like for high temperature heat by steam turbines. The assumptions about efficiencies are the same as for the cogeneration in households and commercial buildings, 50% for thermal and 30% for electrical energy.

Hydroelectric Power Plants

The graph below shows maximum fraction of power that can be produced by a hydropower plant in a certain month in Kanto. This fraction depends on the water flux in big rivers in the regions. We assumed that a maximum electricity production is possible, when the water flux in big rivers is above the average flux of the whole year. If the rivers carry less water, the maximum electricity production goes down as well.

The Figure 44 shows the maximum electricity production by hydropower plants in Kanto. The possible output in April, August, September and October is 100% of the installed power, because the water flux in big rivers was higher than the average flux of the year. What cannot be seen in this graph is that August has the highest water flux of all months of the year. In winter the water flux and consequently the maximum output is much lower than in summer and autumn. These curves have been developed for every region of the simulation. The only region that differs markedly from the others is Kyushu, where the water production is low in August and September and high in the spring.



Source: ERJ.

Figure 44 : The maximum power output of hydropower plants in Kanto.

Geothermal Power Plants

The maximum electricity output of geothermal power plants does not vary over the year, because the supply with geothermal heat does not fluctuate either. Up to the installed amount of producable energy the power plants can be adjusted freely. The amount of installable power plants and their size was published by the Institute for Energy and Total Engineering and was therefore available for the simulation.

Pumped Storage Power Plants

The pumped storage power plants can convert electrical energy into potential energy of water, i.e. they pump water in a reservoir to a higher position using electrical energy. This water can later be used to produce electrical energy again by driving a turbine. Each of these conversion processes has an energy leakage of 10.5%. This leads to an energy loss of 20% for the whole process of storing the energy and reconverting it to electrical energy.

Fast Reacting Power Plants

The fast reacting power plants are hydrogen burning fuel cells (although steam turbines have similar characteristics), which use the hydrogen that has been produced from energy surpluses Their production can be adjusted up to the nominal power output as long as there is hydrogen available. The efficiency for the fast reacting power plants is set to 50%.

6.3) The Dynamics of the ERJ Electrical Model

The energy demand was calculated first. The energy demand of consumers is not adjustable by energy demand management<97>. The electricity production of fluctuating suppliers in every region was then determined and subtracted from the energy demand. The remaining demand had to be covered by adjustable suppliers and storages.

An energy manager was used in the simulation to control the adjustable energy suppliers. This energy manager controlled the cogeneration plants, the hydropower plants and the geothermal power plants. Cogeneration power plants consisted of motors for low temperature heat and steam turbines for high temperature heat. They supplied the industrial sector with enough heat for its processes. Two thirds of these cogeneration plants operated constantly throughout the day. The others were adjusted to meet the electricity demand in the regions. This mode of operation was possible as the heat could be stored in the industry and then consumed when heat was needed.

Firstly, the energy manager powered up the cogeneration plants in the industry in order to cover the remaining electricity demand. If their production did not meet demand, geothermal power plants were used to produce more energy. The hydropower plants were powered up last as their energy production depended on the water level in the dedicated river and was therefore restricted by the amount of usable water.

Regions with a high population density such as Kanto or Kansai are not self-sufficient in energy production. In these regions, the energy deficit is very high because of the large energy demand, with little space for windmills and other energy suppliers. Other regions with a very low population density have a large amount of windmills because of the available space and therefore can export energy to these densely populated regions. This energy exchange has to be managed.

The Import-Export Manager distributed the surpluses over the regions that lacked energy, until all the energy was used or all the regions were fully supplied. The Manager attempted to use the

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97. It would be possible to alter consumer behaviour by sending information to consumers about varying prices according to demand. But this kind of demand management is not included in this program version, although it would improve the energy system.

shortest possible distances in order to minimise transportation losses. If the electricity production was still insufficient, a fast reacting hydrogen power plant with one Gigawatt peak output was powered up. The Manager then emptied the pumped storage plants in order to produce more energy and finally another two Gigawatts of fast reacting hydrogen power plants could be powered up if required. The Manager could also command the energy managers in the regions to produce more energy than required for their own region in order to supply other regions. This ensured that all potentials were used up to a maximum to supply Japan with energy. After many simulation runs this strategy turned out to best meet the supply. This strategy had the advantage that pumped storages always contained some energy for critical times and fast reacting power plants did not burn too much hydrogen.

In this program version of SimRen, Japanese holidays were treated as normal working days, as integration in the simulation was not possible. During the optimisation process it became clear that the introduction of a summer time adjustment would be favourable as the electricity demand peaks would much more closely match the peaks in the solar radiation much better. That is why in the ERJ Electrical Supply Model a time shift of one hour between March 28th and November 31st is included.

Energy supply curves for certain weeks in 1999 were included below to illustrate the dynamic and reliable nature of the supply system<98>. The curves show the supply situation in the third week in January from Monday 14th to Sunday 20th. No shortages occurred during the whole simulation period of one year.

The curves include all energy suppliers and show the power output in Gigawatts over time. The X-axis shows the day of the year and the vertical lines isolate the days from each other at midnight.

The first graph in the figure shows electricity consumption (demand) compared to production (supply). It can be seen that production is always greater than consumption. The energy production is the sum of all energy suppliers shown in the other four graphs. The second graph shows the energy production of geothermal and hydropower plants. Below these adjustable suppliers is a curve containing photovoltaic and wind energy. The fourth curve contains the cogeneration heating plants in the industrial sector and the commercial and residential sectors. The cogeneration plants in the commercial and residential sectors fluctuate due to changes in the outside temperature (Sunday was a very cold day). The high fluctuations in the production occur because the target heating temperature is usually lower at night than during the day, and therefore less heat and less electricity is produced during the night. The development of pumped storage plants and fast reacting power plants is plotted in the last graph. The graph also contains the resulting hydrogen production in this week, although it is not included in the first graph. In this graph, storage charge

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98. All the curves for 52 weeks of the simulation are included in the appendix.

and hydrogen production are drawn negative as they consume energy and can then easily be summed with the producers to the production curve on top.

On the 15th and 16th, the first curve shows a surplus of energy. This energy comes from a very high wind energy and photovoltaic as shown in curve three. Hydrogen was generated from the energy surplus. The second curve shows that the geothermal and hydropower plants produce less energy on those days, as not as much energy is needed. They are not powered down completely because some regions still need this energy.

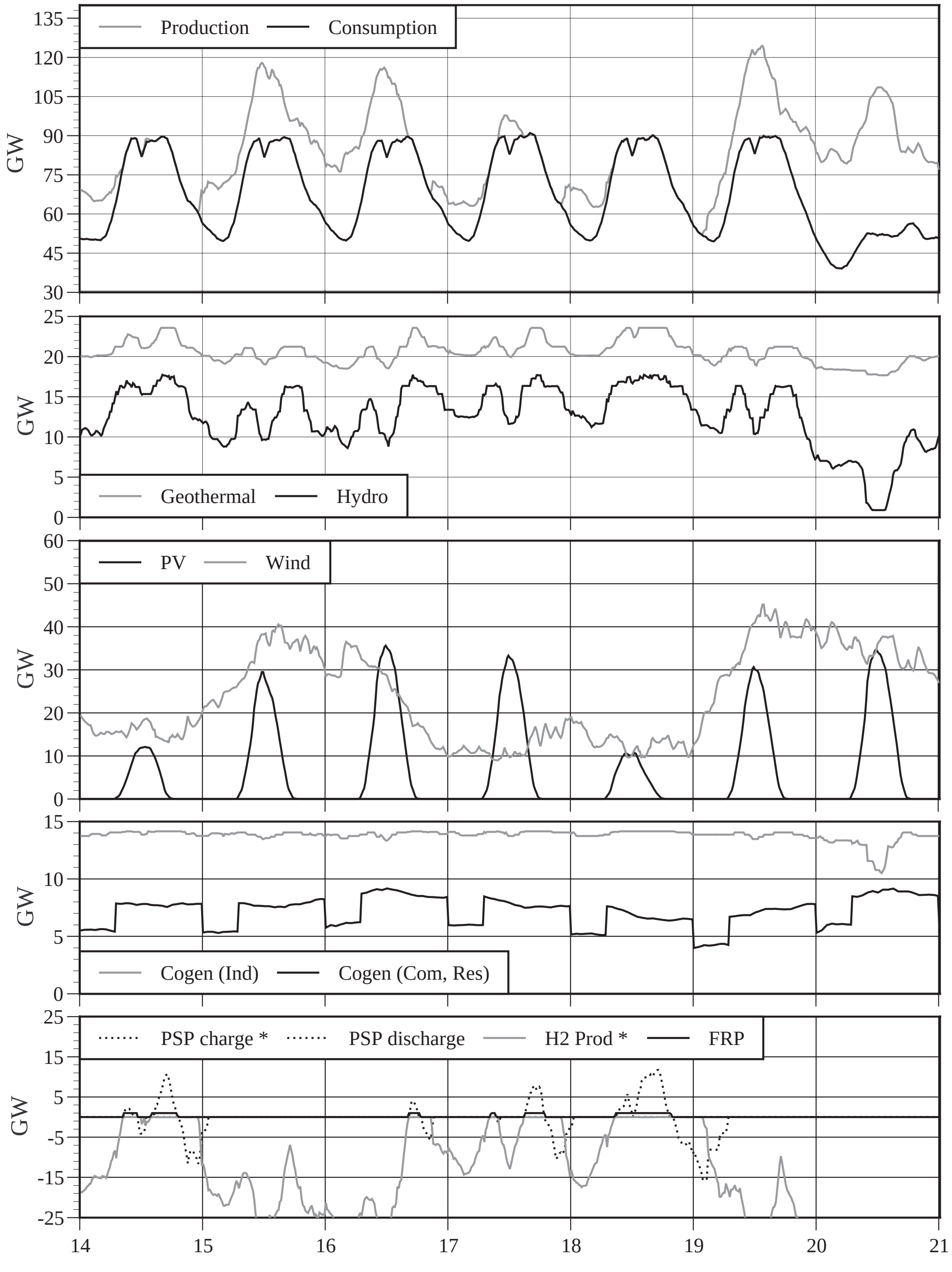
On the 18th, the energy production matches the demand exactly. The ERJ Electrical Supply Model achieved this by adjusting the hydropower and geothermal power plants. The wind and photovoltaic production is much lower on Friday than on the other days. Therefore the adjustable suppliers have to run at full capacity. Of particular note is the fourth graph, which shows the charging and discharging of the pumped storages and the fast reacting power plants. As described above, the fast reacting power plants produce one Gigawatt before the storages are powered up. The pumped storages were then the last technology to prevent Japan from having an energy deficit but, as the graph shows, they were capable of providing the missing energy (see Friday evening) and they were replenished when a surplus of energy became available (see Friday night).

Sunday 20th shows what happens if far too much energy is available. On Sundays the energy demand is always lower than during the week because most of the offices are closed and many industry branches do not work. As this does not affect the fluctuating energy suppliers, most Sundays are oversupplied with electrical energy. The storages are filled mostly over the weekend and can be used again to fill energy deficits. All the adjustable energy suppliers are powered down. Even the production of cogeneration plants in industry can be reduced as shown in curve four.

By analysing these curves, the electrical energy supply system was optimised until it was finally proved that a complete supply of Japan with electrical energy from renewable sources was possible. Two other weeks were also included to show the behaviour in summer and autumn.

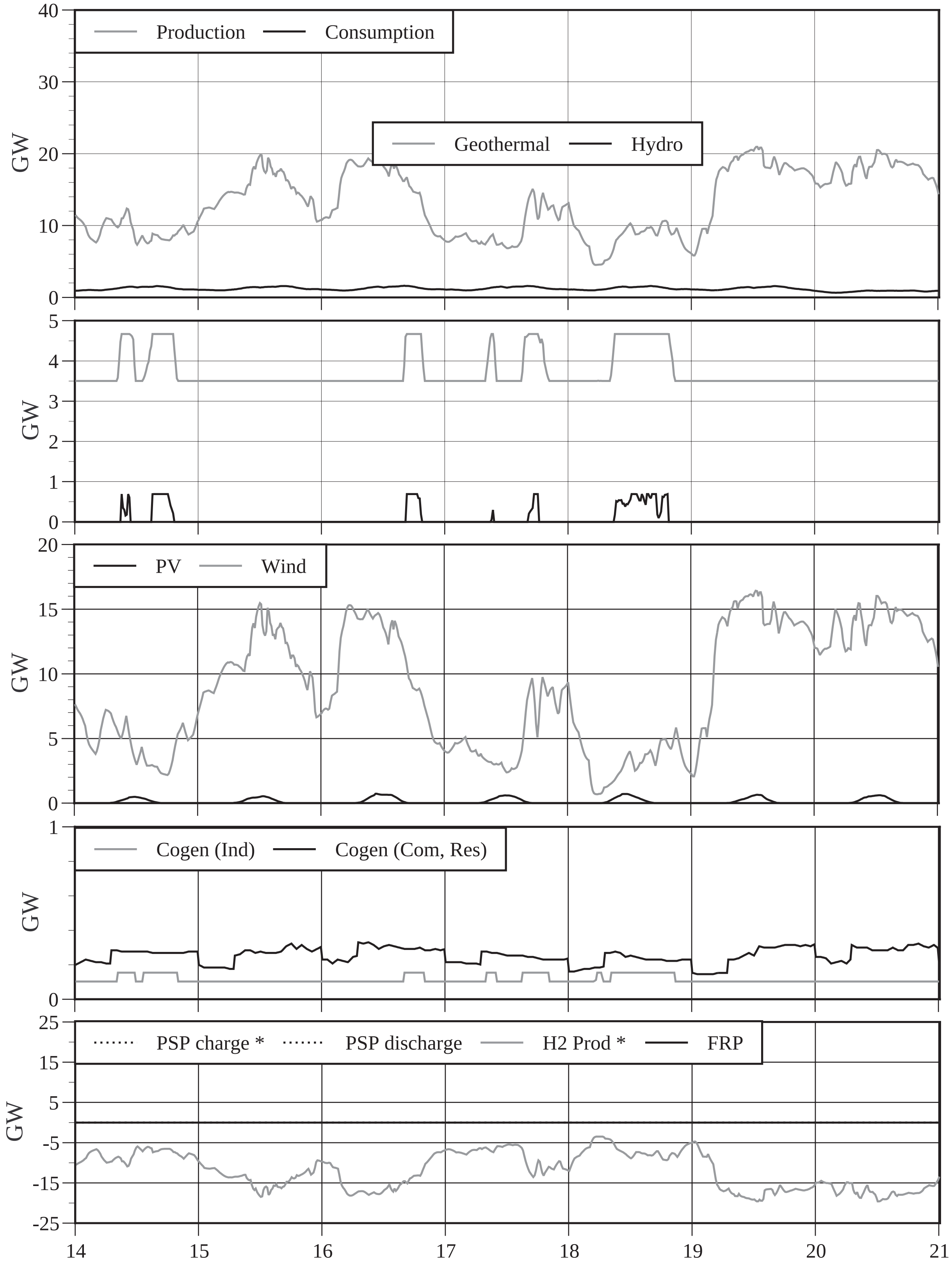
The set of curves above show the region Hokkaido West, where the energy production exceeds the energy consumption most of the time. The graph shows the immense amount of electricity that is produced by windmills and geothermal power plants, because there is such a high potential in Hokkaido West. The photovoltaic electricity production is very low, because Hokkaido has a low population density and therefore very little area for photovoltaics. Energy production by cogeneration is very low for the same reason. On days when the energy production by fluctuating suppliers is low (like Friday or Monday in this week) the geothermal power plants are powered up, although there is no energy needed in Hokkaido West. Even the water power plants produce energy at those times.

The next set of graphs above shows the same week in Kanto. The proportions are reversed in this region, because the population density is extremely high and therefore the spaces for windmills are few. In the week that is shown the energy demand can be met only on Sunday, because the energy consumption is lower than during the week. Due to the high population density the suitable area for photovoltaics on buildings or parking lots is very big. This leads to high energy production by photovoltaic areas. The high industrialisation leads to a large number of cogeneration power plants that also supply the region with energy, but the extremely high energy demand and the few wind mills lead to a undersupply that has to be met by the other regions. In the shown week the geothermal and hydro power plants can only be powered down on Sunday. On Thursday, when the photovoltaic energy production is very low even the pumped storages have to be discharged.



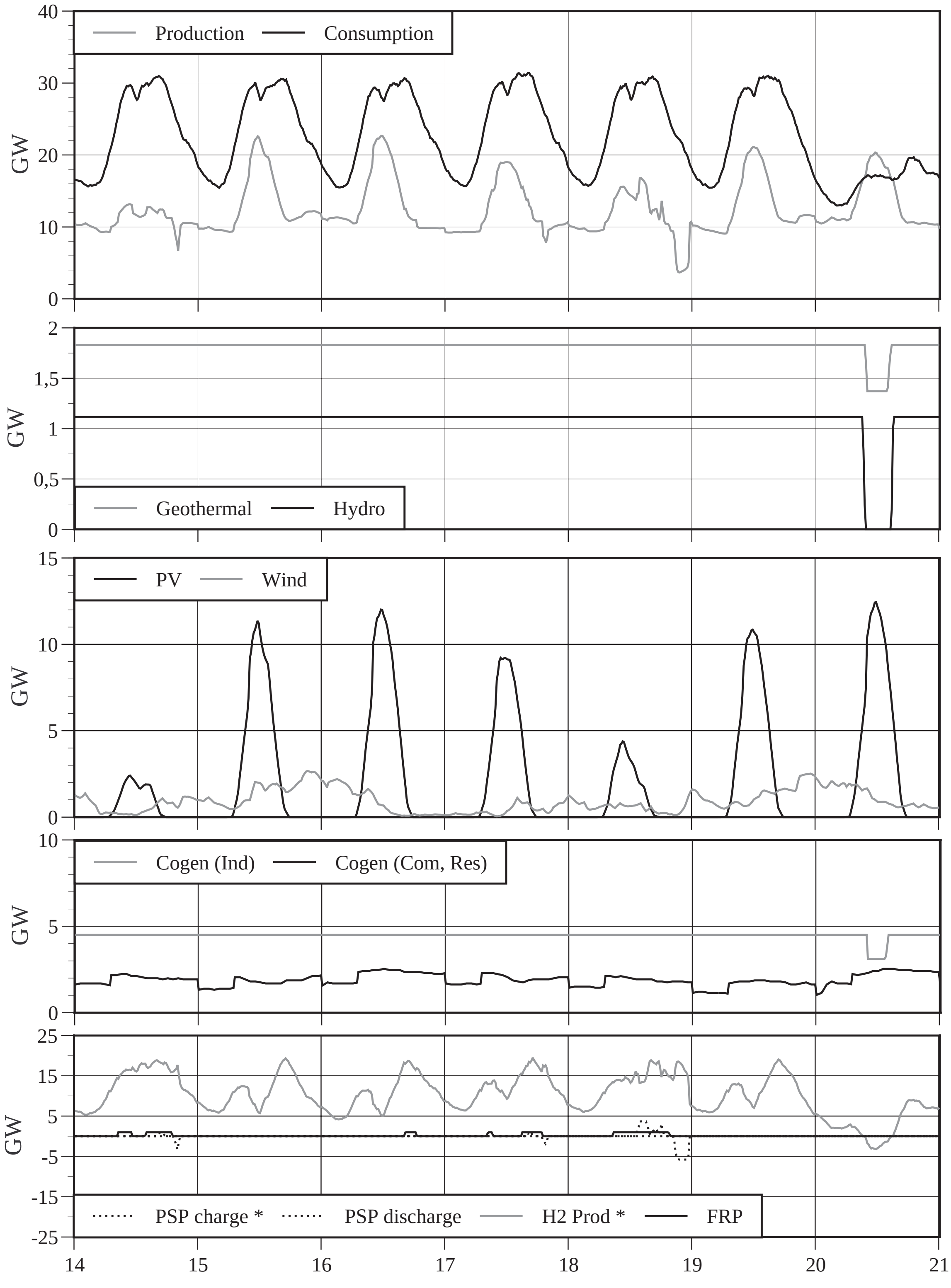
Source: ERJ.

Figure 45 : Energy supply and demand over one week in January in gigawatts.
The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower



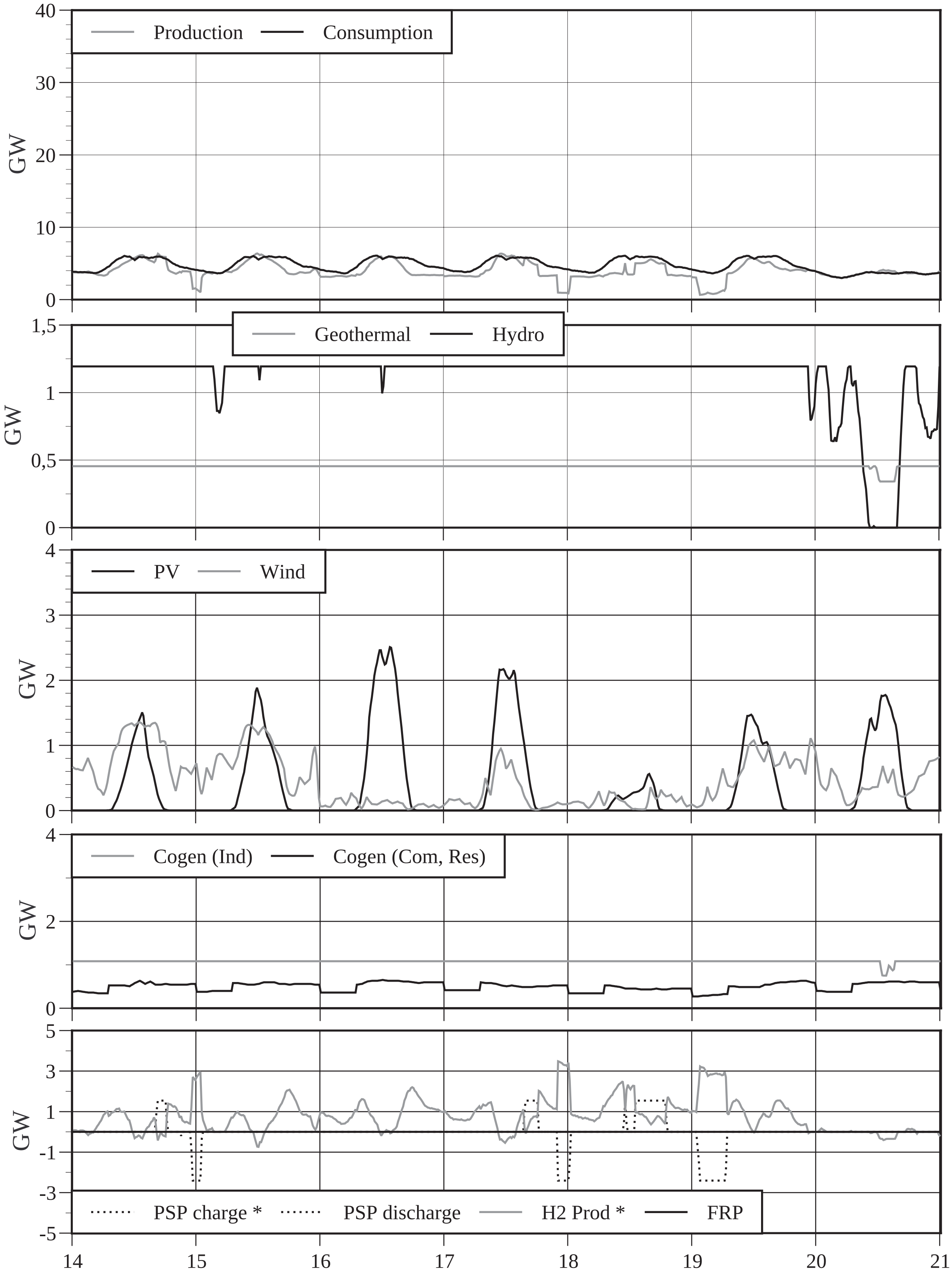
Source: ERJ.

Figure 46 : Energy supply and demand in Hokkaido West over one week in January in Gigawatts.The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower



Source: ERJ.

Figure 47 : Energy supply and demand in Kanto over one week in January in Gigawatts. The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower



Source: ERJ.

Figure 48 : Energy supply and demand in Chugoku over one week in January in Gigawatts.The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower

The third set of graphs above shows Chugoku. It is included because Chugoku has an energy production that nearly supplies the energy demand out of the region itself. The area that is already sealed allows a high installation of photovoltaic areas and there are many hydropower plants in Chugoku. The energy consumption is only a fifth of Kanto. Thursday and Friday night the storages are filled although the region itself does not produce too much energy. This is because the rest of Japan has an energy surplus. And during the day the Import-Export manager orders the storages to produce energy in order to supply Japan. The storages are not discharged when Chugoku is undersupplied but if energy is needed for Japan as a whole.

By analysing these curves, the electrical energy supply system was optimised until it was finally proved that a complete supply of Japan with electrical energy from renewable sources was possible.

The curves of all 52 weeks of the year 1999 are included in the appendix. It is interesting to look at the 2nd week in April, because the energy production by wind parks and photovoltaic areas is very high in this week and the supply exceeds the demand nearly the whole week. The effects of the wind and irradiation can also be seen in the 3rd week in August, because in this week the energy production by these sources is very low and the adjustable suppliers have to cover the demand. It can be seen that the storages are charged nearly every day during the day and discharged during the night. And the fast reacting power plants have to supply the adjustable suppliers in order to meet the demand.

6.4) Conclusions of the Simulation

Using the SimRen simulation of the ERJ Electrical supply Model, it has been proved that Japan can cover its whole electrical energy demand with renewable energy sources that are available within Japan.

The installed capacities and the full load hours of the technologies in the ERJ Electrical System are summarised in the table below. Fast reacting power plants and pumped storage power plants have the least full load hours, as they are only used when the other technologies cannot cover the energy demand. Wind turbines and cogeneration in the commercial and residential sectors have low full load hours compared with the other technologies because they are not adjustable, and depend on wind speed and outside temperatures. The simulation’s full load of 2,890 hours is quite high compared with windmills actually installed. This is because the amount of windmills installed offshore is very high. Cogeneration has full load hours of 8,573, which is certainly high, but additional backup plants lower this amount. It is important to allow some time for maintenance.

Technology	**Installed Power**	**Energy output GWh**	**Full load hours**
Cogeneration in industry sector	14.2 GW	121,737	8,573 h
Geothermal power plants	25.4 GW	180,645	7,112 h
Water power plants	23.7 GW	125,705	5,304 h
Cogeneration in commercial and residential sector	10.9 GW	38,728	3,553 h
Wind turbines	56.9 GW	164,441	2,890 h
Fast reacting power plants	3.0 GW	1,287	429 h
Pumped storage power plants	19.4 GW	4,055	209h

Source: ERJ.

Table 25 : Renewable energy sources used in the ERJ Scenario One, their installed power, energy output and full load hours

The highest electricity production from wind turbines was on the 9th of January. On that day, wind turbines had a power output of 49 GW, which is 86% of the installed power. Because of the low temperatures, the maximum output of the cogeneration power plants in the residential and commercial sector of 9.8 GW was on February 4th, while in August the output of these plants was only 2.5 GW due to the high temperatures in this month.

Pumped storage plants and fast reacting plants run mainly in the afternoon and evening when the sun sets and photovoltaic production declines. At this time most people come home from work and need energy, which then has to be produced without photovoltaic support. Therefore, the introduction of a summer time is highly recommended and is included in the simulation<99>. The storages are filled mainly during the night and on Sundays, because the energy consumption is very low at these times.

The graph above shows how long certain amounts of energy surplus lasted. This surplus is the energy that is used to produce hydrogen. This means pumped storage and fast reacting power plants are already included in the production. Therefore the graph only shows the overproduction. If we include the Fast reacting Powerplants and pumped storage plants in the optimised energy supply system no energy under supply occurs.

Out of 8,760 hours in a year 91.1% of the time more electricity is produced than the demand. This energy is used to generate hydrogen or stored in pumped water for hydropower. The other 8.9% of time when there is no surplus of energy, the energy production meets the demand exactly. This is possible, because the controllable suppliers can be precisely adjusted, if the fluctuating suppliers do not produce too much energy. In 5,700 of these hours (65% of the year) the energy surplus lies between ten and 30 GW. As the graph shows a surplus of more than 40 GW is very rare (only

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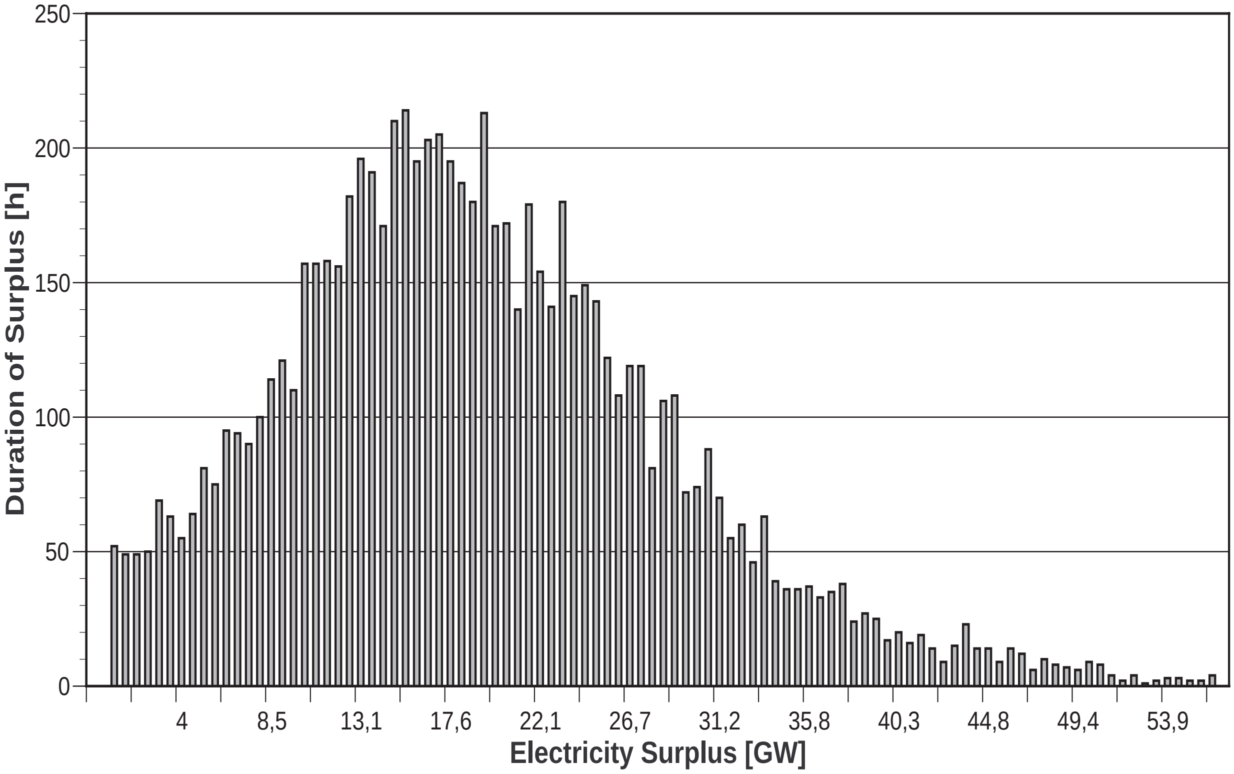
99. The introduction of “summertime”, sometimes known as “daylight savings” artifically sets the clock forward during summer months to enable people to make the most of daylight in the working day and immediately after work. It also has the effect of adjusting peak demand time of day favourably for solar power.

three percent of the year). An overproduction of this size is mainly on Sundays, when the energy consumption is very low.

Using the SimREN simulation of the ERJ Electrical Supply Model it has been proved that Japan can cover its whole electrical energy demand by renewable energy sources that are available within Japan.



Source: ERJ.

Figure 49 : Duration of overproduction of electricity in Japan

7 Conclusions

Bringing together the results of research into energy demand in the *ERJ Demand Model*, energy supply in the *ERJ Supply Models* and the SimRen computer simulation, it was shown that the goal of supplying Japan with a 100% renewable energy system, based on regional and external sources, has been achieved. Furthermore, a study of six possible scenarios demonstrated the options available in order to supply Japan with up to 100% energy from regional sources.

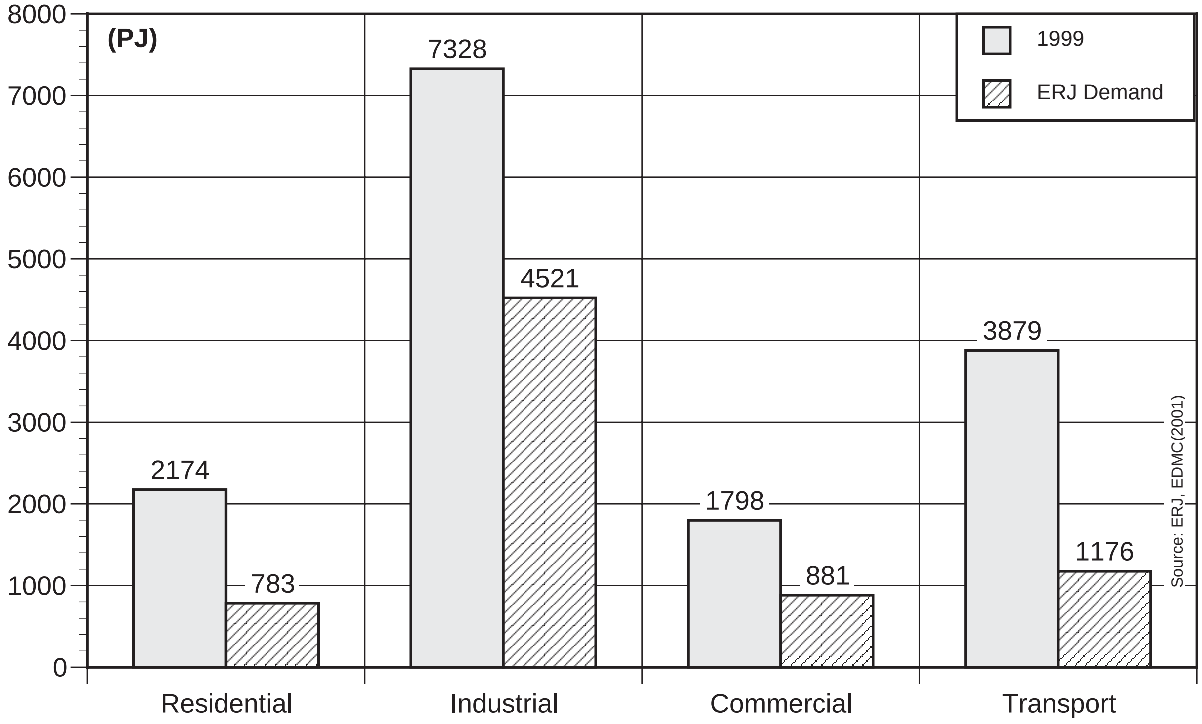
7.1) Demand

Japan is one of the most advanced countries in the world in terms of its energy efficiency, but nonetheless improvements using best available technologies results in a significant reduction in final energy demand of about 50% in the scenarios (from over 15,200 PJ in 1999 to nearly 7,400 PJ in Scenarios One, Three and Five, and to 5,850 PJ in Scenarios Two, Four and Six).

This reduction is a conservative estimate of the potential savings as a number of factors that would have helped reduce demand were not included, including possible industrial structural changes and application of prototype highly efficient technologies. The study did include studies of a decline in the Japanese population in three scenarios<100>. Employment in Japan is moving away from industry towards the service sector. New jobs in information technology, working from home, changing travel patterns and new methods of communicating will help to reduce energy demand<101>. Japanese society is also changing its expectations regarding affluence, with more people valuing free time above wealth and possessions in a trend towards sufficiency.

In addition, a huge energy saving potential exists with material optimisation, reduction, substitution, and product intensification, increasing product longevity and recycling. The concept of resource optimisation<102> is known as Factor 10. Schmidt-Bleek and the Factor 10 Club challenges industrialised nations to drastically reduce depletion of resources (and hence energy use). The concept closely follows the analysis of resource use and optimisation, known as MIPS (material input per unit of service), which demonstrates that a product function can have a much lower specific material requirement per unit of service.

100.National Institute of Population and Social Security Research (2001).
101.Statistics bureau and Statistics Centre, Ministry of Public Management, Home Affairs Post and Telecommunications (2001).
102.Schmidt-Bleek, F. (1993) and Factor 10 Club (1994).



Source: ERJ, EDMC(2001)

Figure 50 : Projected Japanese final energy demand according to the standard (1999) and the *ERJ Demand Model*

A basic overall reduction in final energy demand from nearly 15,200 PJ to under 7,500 PJ was determined, a reduction of over 50%, by introducing BAT in all sectors.

7.2) Supply

The *ERJ Supply Models* can produce all the energy using a combination of renewable energy technologies from regional and external sources or purely regional sources. Scenario One is described in detail in this report as this scenario is used to show the reliability of the system through simulation.

Electricity: In Scenario One, the electrical production (based on regional renewable sources without including fuel burning power plants) amounts to about 94% of the demand requirements. Taking fuel burning power plants into account, the electrical production of Scenario One supplies 122% of demand. This includes the surpluses that are used for hydrogen production. Any fluctuations in electricity production can be fully compensated by a combination of renewable energy technologies and an intelligent control and exchange structure. Energy supply is shown to be as reliable as with any conventional system. The other scenarios have a higher surplus. Solar-thermal plants are employed in Scenarios Five and Six for the supply of electricity for hydrogen production.

Heat: The combination of solar collectors and cogeneration plants utilised in Scenario One can cover the demand for low temperature heat in the industrial sector as well as in the commercial and residential sector. The gross heat production of solar-thermal systems in these sectors slightly exceed heat demand but heat losses due to storage and transport of heat mean that more heat has to be supplied by small cogeneration systems. The resulting total heat production amounts to 119% of the heat demand. The share of solar produced low temperature heat in the industrial sector is about 92% of requirements.

Steam turbines used in industrial cogeneration can produce about 30% of the industrial demand for high temperature heat. Fuels from renewable sources supply the deficit.

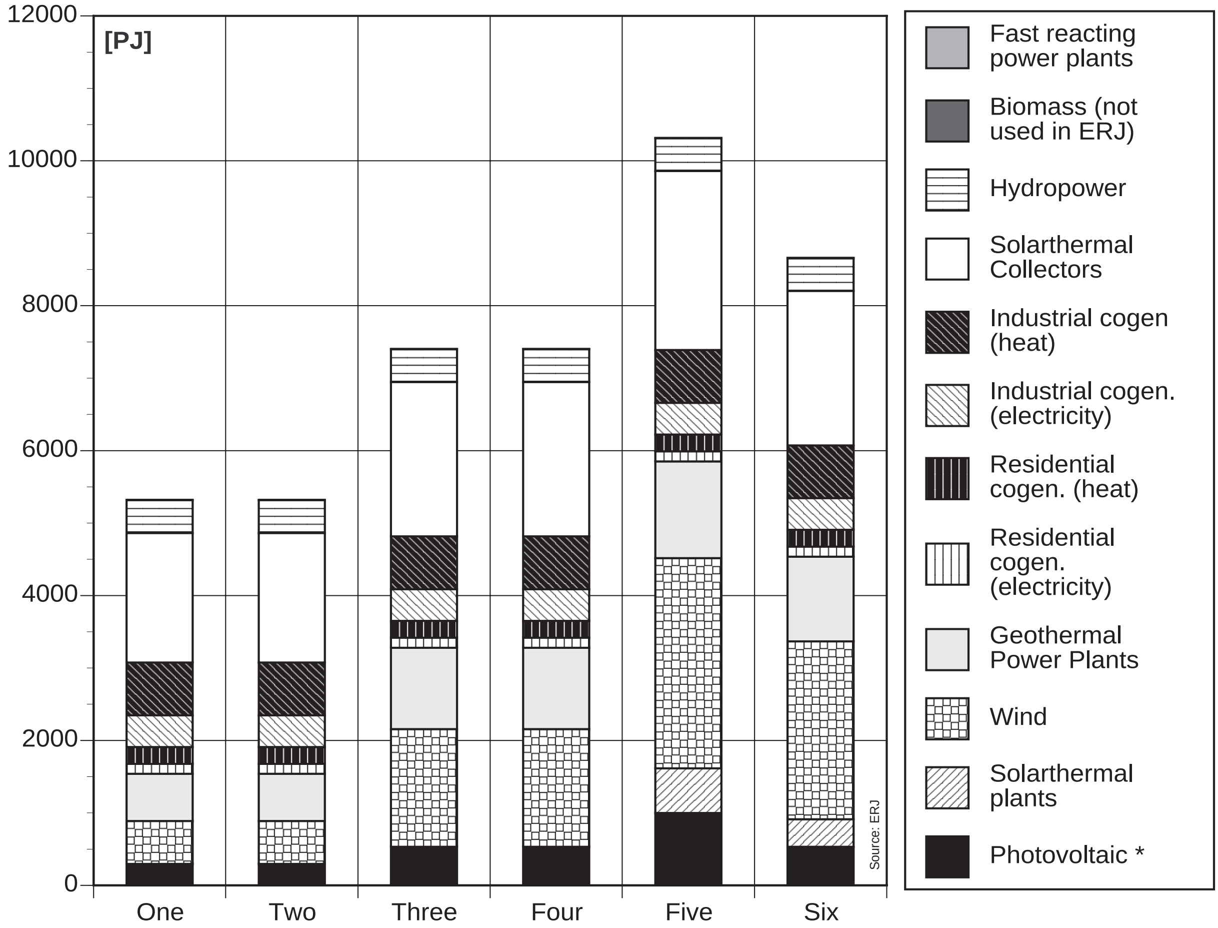
Fuels: The fuel demand for heat and electricity production of cogeneration plants in Scenario One is 1,920 PJ, of which about 370 PJ of hydrogen is produced by the supply system itself, leaving the rest to be supplied from other sources. About 1,980 PJ is required for the production of high temperature heat in the industrial sector and approximately 1,180 PJ is needed for transport.

Altogether about 4,700 PJ of hydrogen equivalent fuel remains to be produced from other sources in Scenario One. Hydrogen can be produced by the increased use of domestic renewable sources, such as wind power, photovoltaics and solar power plants as discussed in the scenarios in the supply chapter

In Scenario One the electrical output of photovoltaics, wind power, hydropower and geothermal energy supplies about 48% of the primary energy production. Solar-thermal collectors produce an additional 14%. Renewable fuels account for about 38% of primary energy production; this includes three percent of the primary energy that comes from domestic hydrogen production.

The amount of fuels imported in Scenario One represents 20% of the amount of energy imported into Japan in 1999.

The diagram below shows the percentage of regional sources compared to imports in the scenarios. Scenario One is the scenario described in detail in this report, whereas Scenarios Five and Six both show a 100% regional energy supply for Japan.



Note: This is the production of electricity and heat in the installed power plants. Biomass is set to zero. Sustainably produced biomass holds enormous potential, but the amount available was unknown at the time of publication of this study.

Figure 51 : Domestic energy production in all “Energy-Rich Japan” scenarios

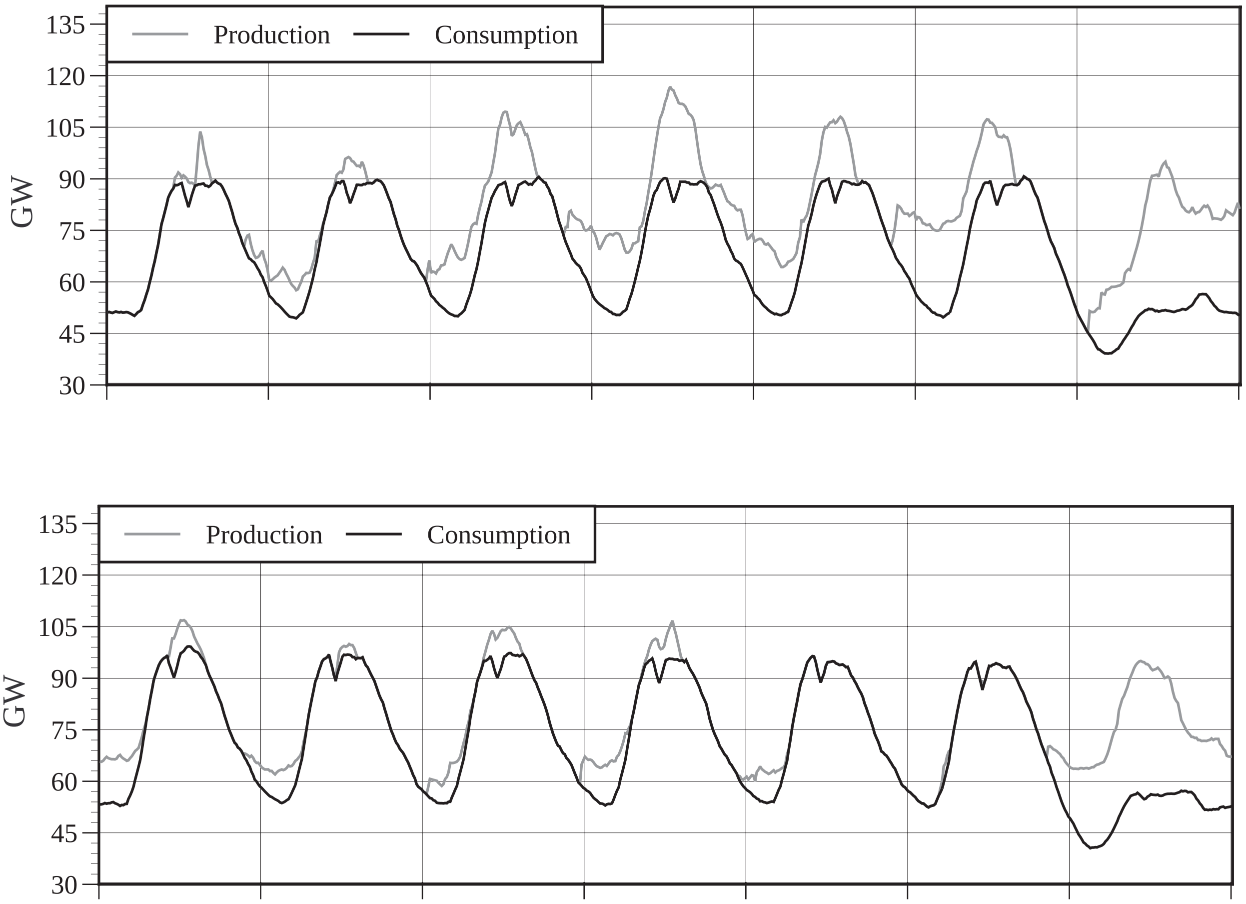
7.3) Simulation

Japan was divided into 12 regions, which were supplied by information from 153 weather stations across the country. Using the SimRen simulation with a 15-minute resolution, it was proved that Japan is able to reliably cover its whole electrical energy demand throughout the year using domestically available renewable energy sources as described in *ERJ Supply Model* 1. The other scenarios have and use more energy and are therefore more reliable.

Fast reacting power plants and pumped storage power plants have the least full load hours, as they are only used when the other technologies cannot cover the energy demand. Wind turbines and cogeneration in the commercial and residential sectors have low full load hours compared with the other technologies because they are not adjustable and depend on wind speed and outside temperatures.

The highest electricity production from wind turbines was on the 9th of January. On that day wind turbines had a power output of 49 Gigawatts, which is 86% of the installed power. Because of the low temperatures, the maximum output of the cogeneration power plants in the residential and commercial sector of 9.8 GigaWatts was on February 4th, while in August the output of these plants was only 2.5 GigaWatts due to the high temperatures in this month.

Pumped storage plants and fast reacting plants run mainly in the afternoon and evening as the sun sets and photovoltaic production declines. At this time most people come home from work and need energy, which then has to be produced without photovoltaic support. Therefore the introduction of a summer time is highly recommended and was used in the simulation. The storages are filled mainly during the night and on Sundays, because the energy consumption is very low at these times.



Note that supply always meets or exceeds demand. Excess supply was used for hydrogen production or pumped water storage.

Source: ERJ.

Figure 52 : ERJ supply and demand in GigaWatts, showing the first week in January and third week in September in Scenario One

8 Policy Recommendations

Without political support, even economically competitive renewable energy technologies remain at a competitive disadvantage as a consequence of distortions in energy markets created by decades of ongoing financial, political and structural support to traditional polluting technologies. Networks for power, heat, and transport have been developed over the course of a century based on use of fossil fuels and more recently for nuclear power. The switch to renewable energy will require strategic policy intervention to facilitate and accelerate the transition and political action will be needed to ensure full achievement of the economic and environmental benefits of renewable energy.

Efforts toward the introduction of a comprehensive market of renewable energy and efficient technologies include full-cost energy pricing, environmental regulations, tax incentives, codes and standards, and public education. Specifically, the following areas of action are required:

Demand Policies

- Mandatory Efficiency labelling and Standards
- Economic incentives for efficient devices
- Minimum standards in new buildings, including insulation, solar-thermal and PV
- The retrofitting of existing buildings
- Establishment of an ‘energy efficiency’ agency with a clear decision making authority

Supply Policies

- Establishment of legally binding targets
- Creation and definition of stable returns for investors
- Removal of market distortions
- Reformation of the electricity and fuel markets to accommodate environmental considerations

Transportation

- Taxation based incentives for lower consumption private vehicles
- Measures to increase the uptake of public transport
- Improved town planning

Hydrogen Economy Transition Policies

- Research and development

- Demonstration of the technology;
- Hydrogen economy target dates.
- Development of hydrogen infrastructure.

All recommendations must address both the supply and the demand side of the energy system in order to have an effect. To be effective, any set of policy changes must consider the following issues:

8.1) Increasing Energy Efficiency

Labelling and Standards

All appliances should be graded with reference to best available technology energy efficiency allowing buyers to make informed choices. The state must also set minimum standards for products in the market place that excludes inefficient products. This standard must be reviewed regularly to reflect improved technology available.

Economic Incentives for Efficient Devices

Incentive should be provided to influence consumers' actions by preparing incentives for the purchase of efficient appliances. For example, the Danish Electricity Saving Trust in Denmark has had much success in using a tariff of 0.07 yen per kWh of power rates to fund such measures as transfer of electric heating to geothermal heating, energy efficiency labelling of electrical appliances, and campaigns to promote efficient appliances and use of rebate programs.

Energy Efficiency Standards and Requirements for Buildings

In order to promote energy savings in buildings a standard for the energy efficiency of buildings must be established, covering elements such insulation, double-glazing, efficient heating, cooling, lighting and the use of solar energy for heat and power. Further compulsory thresholds for new buildings covering both thermal efficiency power efficiency and provision of solar hot water heating and solar PV must be incorporated into the building regulations.

Note: The “Stop Global Warming! Tokyo Operation” announced by the Tokyo Metropolitan Government in February 2002, made the appeal to save the future of mankind and the earth 100 years from now” and proposed comprehensive regulation of energy consumption especially focusing on the industrial sector. In particular, this involves the introduction of obligations for large-scale offices and factories to reduce carbon dioxide output, issuing and creating a market for CO2 reduction certificates for energy saving activities, the installation of wind power, and planting of forests. As a megalopolis that counts for one percent of the CO2 output of developed nations, this is a great step that eclipses the plans of the national government<103>.

The Retrofitting of Existing Buildings

Subsidies and loans are required for the promotion of retrofitting of existing buildings. Furthermore, existing buildings should be regularly audited and managed to meet energy targets. It is important to promote the refitting and retrofitting of domestic, public and commercial premises with energy efficient materials and fittings for doors, windows, walls, water heating, lighting, and space heating, for example.

Energy Efficiency Funds

Lastly, we recommend the establishment of an energy efficiency fund, secured by the reallocation of proceeds from the electricity and gas network carriers and/or from a part of an eco-tax. The proceeds should serve the financing of competitive campaigns, from measures and programs to the market support of efficiency technologies and services as well as motivation and information campaigns. A central administration and/or implementing institution would preferably be an energy efficiency agency, similar to the model of Great Britain or Denmark, which cooperate with energy enterprises, energy agencies, providers of energy-efficient technology and other market participants. Also incentives for energy enterprises should be created for accomplishing Demand-Side Management programs (DSM) with their customers. The goal is to accelerate and contribute to the market transformation through energy cost reductions in all consumer groups in favour of efficiency techniques.

8.2) Supply Side Recommendations

Establish Legally Binding Targets for Renewable Energy and Energy Efficiency

In recent years an increasing number of countries have established targets for renewable energy, as part of their greenhouse gas reduction policies. These are either expressed as specific amounts of installed capacity or as a percentage of energy consumption.

The most ambitious target has been set by the European Union. In 2001 the European Council and the European Parliament adopted a Renewable Energy Directive establishing national targets for each member country, although these targets are not legally binding provided compliance is dem-

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[103] Tokyo Metropolitan Government (2001).

onstrated. The Directive aims to double the share of renewable energy in the energy mix from 6% to 12% by 2010, equal to 22% of European electricity consumption.

With most of the large hydropower potential already exploited in Europe, the majority of the increase in renewable energy in Europe will come from solar, biomass, wind and small hydroelectric energy. The same is true of Japan.

Renewable energy targets are most effective if they are based on a percentage of national consumption. This creates incentives to reduce consumption as well as create sustainable supply. If these targets are set as short term targets and long-term milestones this acts as a guide to identify where immediate policy changes are required to achieve 5-year, 10-year and 20-year targets. However, targets have little value if they are not accompanied by policies, which achieve a level playing field in energy markets, eliminate market barriers and create an environment that attracts investment capital.

Defined and Stable Returns on Investments

Policy measures adopted by Governments need to be acceptable to the requirements of the investment community in order to be effective. There are two key issues here:

- The price for renewable energy and efficient technologies must allow for risk-return profiles that are competitive with other investment options
- The duration of a project must allow investors to recoup their investment

Fixed Tariff Systems

Fixed tariff systems have proved to be the most effective instrument for the promotion of renewable energy.

Tariff systems based on a fixed price paid per unit of energy produced have been enormously successful at catalysing renewable energy markets and are enshrined in law in Germany and Spain.

As production costs decline, for instance as a result of improved technology and economies of scale, the less economic projects become profitable, expanding the deployment of renewable energy further.

The most important advantage of fixed price systems for renewable energy is that they facilitate planning of new renewable energy plant for the investors in renewable energy. The challenge in a fixed price system is fixing the “right” price. The disadvantage is the political uncertainty that may arise over how long the system will continue, which means that investors must calculate a risk premium in case the price falls during the life of the project. Germany has avoided the problem in the 1999 revision of the Stromeinspeisungsgesetz (Act on the Sale of Electricity to the Grid) by guaranteeing payments for 14 to 20 years.

Renewable Portfolio Standards (RPS)

RPS systems are typically used in the power sector, but can also be used in other areas like transport fuels. Under an RPS, such as the one operating in Texas or the UK, power companies or electricity customers are obliged to buy a number of green certificates in proportion to their total electricity consumption. The certificates are bought from the producers of renewable energy who will receive certificates in proportion to their electricity delivery, for example one certificate per delivered kWh. The system implies that part of the payment to the project owners is made in a special currency - green certificates. The price of the certificates is set in a market where buyers' demand and seller's supply determines the price. For fuels an equivalent displacement in the fuel mix is made, for example bio-ethanol mixed with the transport fuel.

An RPS can be technology neutral or broken down further into fractions to come from specific technologies wind, solar etc. The RPS market only starts, however, if penalties for not purchasing green certificates are sufficiently high to deter non-compliance. To ensure sustained investment, the RPS needs to include long-term market expansion.

One drawback of a system with specified fixed quantities of renewable energy is that the targets may not be reflective of the speed of industrial progress and the increasing competitiveness of renewable energy, and hence the standard could become a cap on development. A target which is not sufficiently high or dynamic soon becomes a constraint.

Competitive Bidding, Tendering or Auctions

Governments define a fixed amount of funds and tenders for projects, which can be technology neutral or specific. It accepts projects tendered up to the level of the available funds. Under auction, or tendering systems, power purchase agreements are entered into for an agreed period – typically 15 years. In this system there is a politically decided quantity, usually a constantly increasing quota of electricity from renewable energy sources which the power companies or the customers must purchase. This is achieved by letting the suppliers of energy products from renewable energy sources compete for the contracts.

The system, to a large degree, removes much of the political risk for investors if the price is agreed upon for a defined period such as 15 years, and the energy purchasing agreement is enforced under civil law.

Tendering systems with high penalty clauses appear to be economically efficient, but they are probably only workable for large investors, and not smaller operators such as co-operatives or individual owners, at least not unless they are part of a larger risk-sharing arrangement through a joint project organisation.

Where targets and/or penalties are too low, a buyers' market is created and experience has shown that the aggressive competition created for lowest price leaves only small margins that will deter investors and force developers to use only a limited set of highly competitive projects.

Investment Subsidies

With subsidies for renewable energy projects, support is usually given on the basis of the rated capacity of a generator or energy production plant. These are typically used at an early stage of development when little or no additional incentives are in place. These systems can be problematic because a subsidy is given whether or not production is efficient. The international tendency is to avoid investment subsidies as a sole policy choice and adopt either fixed price tariffs or an RPS system, which essentially fix either price or quantity.

Furthermore, because such systems are often based on the availability of government funds and ongoing political goodwill, due to the short-term nature of governments, they may not provide the long-term security and stability that industry and financiers require.

There are sectors where, for example, fixed tariff systems do not work such as the retrofitting of buildings. This requires support in the form of subsidies for the fitting of renewable and efficient energy systems.

Incentives for Public Participation in Renewable Energy Ownership

One of the driving forces behind the development of wind power in Denmark was the creation of wind power cooperatives in which the residents of a particular area invest. The concept of the assets of a region providing a financial return to the region is the foundation for local people using wind power in Germany and Denmark. However, in order to succeed with these efforts, public assistance policies such as those mentioned previously are essential.

Emission Caps

Whereas taxation provides a pre-defined penalty for polluting, an emissions cap can set a pollution standard but leaves it to the market to decide how best to comply with that standard. This can also allow for the introduction of energy saving measures, which are often cheaper than new low-emission generating capacity and will therefore be a slower route to renewable market development. The Kyoto Protocol is a system based on emissions caps, although it does allow for the use of flexible mechanisms that effectively raise the level of the emissions cap.

This system is economically efficient in the short term; however it does not set out the pathway to most rapidly develop the renewable energy industries required for fossil fuel and nuclear phase out, making it economically inefficient in the longer term.

Removal of Market Distortions

In addition to market barriers there are also market distortions, which block the expansion of renewable energy. These distortions are in the form of direct and indirect subsidies, and the social cost of externalities currently excluded from costs of traditional, polluting energy from nuclear and fossil fuels. Power prices today do not reflect the full costs of energy production, or the full environmental benefits of renewable energy. Two factors are important here:

- End subsidies to fossil fuel and nuclear power sources

Conventional energy sources receive an estimated $250-300 billion in subsidies per year world-wide, and therefore markets are heavily distorted. The Worldwatch Institute estimates that total world coal subsidies are $63 billion, in Germany the total is $21 billion, including direct support of more than $70,000 per miner. Subsidies artificially reduce the price of power, keep renewable energy out of the market place, and prop up increasingly uncompetitive technologies and fuels. Halting all direct and indirect subsidies to fossil fuels and nuclear power will create a more level playing field across the energy sector. For example the 1998 OECD study “Improving the Environment through Reducing Subsidies” noted that,

“Support is seldom justified and generally deters international trade, and is often given to ailing industries. (...) support may be justified if it lowers the long-term marginal costs to society as a whole. This may be the case with support to ‘infant industries’, such as producers of renewable energy.”

The 2001 report of the G8 Renewable Energy Task Force goes further, stating that “Re-addressing them [subsidies] and making even a minor re-direction of these considerable financial flows toward renewable energy, provides an opportunity to bring consistency to new public goals and to include social and environmental costs in prices.” The Task Force recommends “G8 countries should take steps to remove incentives and other supports for environmentally harmful energy technologies, and develop and implement market-based mechanisms that address externalities, enabling renewable energy technologies to compete in the market on a more equal and fairer basis.”

- Internalise social and environmental costs of polluting energy

The real cost of energy production by conventional energy sources includes expenses absorbed by society, such as health impacts, local and regional environmental degradation – from mercury pollution to acid rain causing environmental, infrastructure and human health damage – as well as global impacts from climate change. For example, more than 30,000 Americans die prematurely every year due to emissions from electric power plants. It also includes the waiving of nuclear accident insurance that is too expensive to be covered by the nuclear operators; for example the Price-Anderson Act, which limits the liability of US nuclear power plants in the case of an accident amounts to a subsidy of up to $3.4 billion annually. As with the other subsidies, such external costs must be factored into energy pricing if the market is to be truly competitive. This requires that governments apply a "polluter pays" system that charges the emitters accordingly, or applies suitable compensation to non-emitters. Adoption of polluter pays taxation to polluting electricity sources, or equivalent compensation to renewable energy sources, and exclusion of renewable energy from environment related energy taxation is important to achieve fairer competition on the world's electricity markets.

Electricity Sector Market Reform

For the power sector specifically, essential reforms are necessary if new renewable energy technologies are to be accepted at a larger scale. These reforms have to remove barriers to renewable energies.

Current energy legislation on planning, certification and grid access has been built around the existence of large centralised power plants, including extensive licensing requirements and specifications for access to the grid. This favours existing large-scale electricity production and represents significant market barriers to renewable energy. Furthermore it does not recognise the value of not having to transport decentralised power generation over large distances.

Among other measures, the reforms needed to address market barriers to renewable energy include:

- Streamlined and uniform planning procedures and permitting systems and least cost network planning;
- Fair access to the grid at fair prices and removal of discriminatory access and transmission tariffs;
- Fair and transparent pricing for power throughout a network, with recognition and remuneration for the benefits of embedded generation;
- Unbundling of utilities into separate generation and distribution companies to avoid exclusion of third party generators or green power retailers;
- The costs of grid infrastructure development and reinforcement must be carried by the grid management authority rather than individual renewable energy projects;
- Disclosure of fuel mix to end-users to enable consumers to make an informed choice of power source.

Liquid and Gaseous Fuel Sector Market Reform

Renewable fuels can be created directly from sustainable biomass or transferred into energy carriers such as hydrogen. The *ERJ Model* uses hydrogen, but does not rule out the role of biofuels. In either case, reforms are required in the liquid and gaseous fuels sector to facilitate the transition to renewable based fuels.

- Removal of Market Distortions

As with the power sector, any market distortions must be identified and removed if emergent technologies are not to be held out of the fuel market. Typical distortions include the use of subsidies to lower the price of fuel – often used to stimulate economic activity, but with serious environmental consequences.

- Full Cost Pricing

A second type of indirect subsidy is the absence of applying externality or pollution costs to the use of fossil fuels. In addition to localised environmental and health costs, which are usually paid for by the taxpayer, the most pressing environmental impact is climate change. The use of a carbon tax on liquid fossil fuels is a useful corrective tool. Note that the UK Non Fossil Fuel Obligation was a carbon tax that also recycled the collected levy to promote renewable energy.

- Infrastructure Development

As with the power sector, the current fuel distribution system has been designed around fossil fuel distribution and will have to be adapted for use for liquid biofuel distribution and the distribution of hydrogen (liquefied or gaseous) in a decentralised energy supply system. The research, development and implementation of these infrastructure changes need to be supported by government incentives and information exchange.

8.3) Transport

Efficient Vehicles

Low fuel prices generate very poor incentives for car manufacturers to create light and efficient vehicles. Taxation law that is tied to the fuel consumption of a vehicle would favour small and light automobiles. One of the reasons the fuel efficiency of passenger cars has not improved much in Japan is that the tax reform of 1989 abolished tax on large passenger cars of over two litres and since then the so-called “3-number plate” cars have continued to increase. Even though the efficiency of individual vehicles has improved, larger cars mean greater fuel consumption, and the effect of this efficiency is negated. Tax reform is therefore required in order to create a clear deterrent to the use of high consumption personal vehicles.

Public Transport

In order to minimize the use of private vehicles, the preparation of a public transport network is essential. Bold measures should be taken such as government assistance for public transport and making public transport highly functional and low or zero cost.

Low Transport Requirement Town Planning

The provision of walking and cycle paths for short distances must also become standard in city planning. As must the design of new dwelling areas that reduce the amount of transport that resident must undertake to live there.

Hydrogen Economy Transition Policies

As this report demonstrates, there is ample renewable energy to meet Japans’ needs. However, a critical requirement in order to make renewable energy suitable for demand is that it can be converted into a storable and transportable 'energy carrier' to supply the demands of the transport sector and for balancing differences between electrical loads and supplies. Hydrogen and fuel cells have emerged as one of the simplest and universally available systems with which to achieve a 100% renewable energy infrastructure.

Hydrogen can be created though the electrolysis of water, stored, pumped through pipelines like gas, carried in tanks in vehicles, and converted into electrical power on demand.

For the full transition to a renewable energy system, a clear long-term political strategy is required for the delivery of the energy carrier infrastructure as well as the harnessing of the renewable energy systems that will supply it.

Political support is vital for the creation of a hydrogen infrastructure as the private sector is focused on short-term financial returns. In addition, cooperation is required on a worldwide level. The transition would be aided by creating a level playing field for renewables, such as the removal of subsides for fossil fuels and nuclear power. There are ten key elements<104> that would aid the transition:

- Research and development
- Demonstrations

104.Dunn, S. (2001).

- H2 economy target dates
- Development of hydrogen infrastructure
- Public-private partnerships
- Full-cost energy pricing;
- Environmental regulations
- Tax incentives
- Codes and standards
- Public education

Much interest in centred on pilot projects, especially in Iceland, where a transition to a hydrogen economy is already underway assisted by Shell, amongst others. Many lessons will be learned from such schemes.

In Japan, the World Energy Network (WE-NET) is investing considerable sums into hydrogen initiatives. Current research is focusing on efficiency improvements, storage systems and infrastructure development. The short-term focus is on hydrogen production using gas reformation, transitioning to hydrogen production from renewable sources over the long-term.

Another important tool for decision makers is scenario building. This will help facilitate short-term and longer-term paths to a hydrogen economy. Scenarios range from a utopian view of full adoption through to a scenario where hydrogen use remains the same as today. The direction taken will largely rely on the extent to which the above ten points are adopted.

According to Shell, the transition in to a hydrogen economy can take two paths: a carbon-free supply using the electrolysis of water, or making the transition through the use of the existing fossil fuel system. The problem with the former is the cost of the renewable energy sources, conversion to hydrogen, plus the infrastructure required for delivery of the fuel. This can only be made possible by incorporating the full environmental costs of fossil fuels and nuclear power. According to Shell, however, „(this approach).. is clearly the best possible system—completely emission free and environmentally benign. The question is how to get there,” Mark Moody-Stuart, Shell CEO.

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10 Appendix : SimRen Simulation of the dynamics of energy systems

The program 'Simulation of Renewable Energy Networks' (SimRen) has been developed in order to study energy systems that are based largely or entirely on renewable sources of energy. SimRen is based on the experience gained while creating scenarios for the European supply area <105>. In the analysis of the dynamics of the scenarios, it was found that the existing tools (simulation programs, database) were not sophisticated enough to make assertions that are precise to the hour or minute about the security of supply of such a system. This meant that only a limited optimization of the system was possible, and the estimates necessary as a consequence probably led to much greater plant capacity being needed in the scenarios than would have been necessary for reliable operation.

With the help of the SimRen simulation, it is possible to model and study in detail the structure of an energy supply system within the simulation environment. SimRen enables one to investigate the dynamics of the system, the optimization of the geographical distribution of the different technologies, and to simulate a country or a supply area over a period of an entire year.

The dynamics of the system are of great interest, since one must ensure that the energy demand can be met simultaneously, especially in the field of electrical power supply. Renewable sources of energy are dependent to a large degree on external weather conditions. For that reason, a large part of the energy supply cannot be controlled, or only to a limited extent. These fluctuations can be compensated for to a large extent by good geographical distribution. Therefore it is important to simulate a high spatial resolution, so as to be able to optimize the distribution of the technologies. If power consumption and power production do not coincide at some point in time, frequency fluctuations or supply bottlenecks can occur in the electricity grid. It is thus necessary to simulate the system with a sufficiently high temporal resolution, so as to examine whether security of supply is guaranteed at all times.

10.1) Necessary temporal and spatial resolution of the simulation

In order to prove that a region can be supplied at all times with electric power from renewable sources, a meaningful temporal resolution of the simulation is important. For example, a temporal

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105.LTI (1998).

resolution of one day would provide few useful results, since insufficient supply during the course of a day, due to fluctuating suppliers, could not be detected. A resolution of one value per hour is the usual resolution in which weather and power-consumption data are available. A resolution at least this fine should be chosen in order to be able to make reliable statements about security of supply. However, in view of the technologies to be simulated, it makes sense to choose a resolution of fifteen minutes, since they typically need that long to react to changes.

A high spatial resolution is decisive for exact investigations of spatially dependent and weather-dependent effects. The effects of a high resolution on the simulated production of wind power becomes clear in the following graphs.

Figure 53 shows the normalized electrical output of nine wind turbines, in an example from the ‘Energy Rich Japan’ study. The black curve is computed on the basis of nine different sets of weather data<106>, while the grey curve is based on only one average set of data. So while the black curve is composed of the weather data at nine different locations, only the weather data for one location were used for the grey curve. The curve calculated using nine different sets of weather data is more even, since wind turbines are scattered about the countryside, and thus each wind turbine does not experience the same weather. The fluctuations of the weather-dependent suppliers cancel one another out in part if a higher spatial resolution is chosen. This results in a substantially higher base load, which corresponds more to real-life operations.

The Figure 53 confirms the hypothesis formulated by other authors that fluctuations in periods less than fifteen minutes are canceled out by a high spatial resolution . However, this smoothing of the curve representing the energy produced only affects fluctuations that propagate spatially, or local fluctuations that do not occur over larger areas.

A meaningful spatial resolution is obtained from the speed of movement of clouds or wind fronts. The spacing between the meteorological measuring points should not be smaller than the distance that a wind front can cover between two measurements. So for a temporal resolution of the weather data of one hour, and an average wind speed of 4 m/s, the weather stations should be located at least 15 km apart.

Another, usually much more decisive, limitation is the existence of correlated weather data in a suitable resolution, on the one hand, and the computing time needed for the simulation, on the other. For the Energy Rich Japan simulation, weather data from 175 weather stations with a resolution of 1 hour was available.

106.Japan Meteorological Agency (2001)

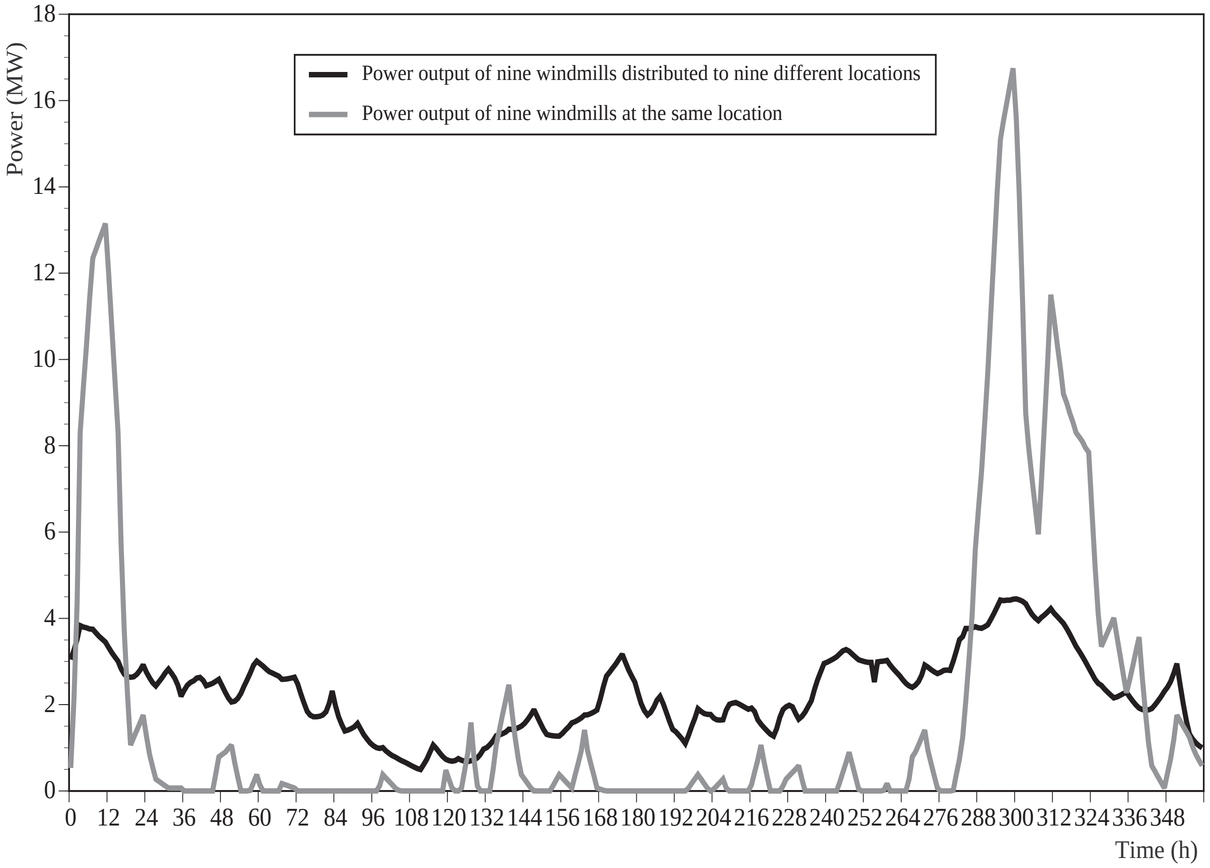

Figure 53 : Power output of several wind turbines computed for different spatial resolutions. Source: ISUSI

10.2) Structure of the simulation model

The simulation is subdivided into energy supply, demand, and distribution models. These three parts have been integrated in a “bottom-up” structure. Just as a real energy supply system is made up of many different energy suppliers and consumers, the simulation is composed of many small units , such as wind turbines, hydroelectric plants, geothermal power plants, or energy consumers, which are combined into regions. In SimRen, a supply area is composed of regions, which each have their own supply, demand, and distribution components. Thus the overall model is built up from the “bottom” (the consumer or supplier) to the “top”, the overall system.

The lowest level of the model in SimRen consists mainly of technologies that convert primary energy into electrical energy or heat. One example for such a technology is a wind turbine that converts the energy of the wind into electrical energy by the wind driving a turbine. The electrical energy can then be transmitted via the electricity grid.

The following are currently available for the simulation: wind, photovoltaic installations, hydroelectric plants, solar thermal power plants, geothermal power plants, biomass power plants, conventional fossil-fuel power plants, solarthermal collectors, peak-load power plants, and cogeneration of electricity and high-temperature or low-temperature heat. Pumped-storage reservoirs and hydrogen reservoirs for storing electrical energy over longer periods are also integrated. However, due to the modular, bottom-up structure, it is easy to add additional components to this nucleus.

There are differing meteorological data associated with the energy suppliers having weather-dependent energy production in the various regions. In principle, an unlimited number of sites with differing meteorological data is possible for each region.

In order to map the dynamics of an energy system realistically, it is necessary to simulate the energy consumption side as well. Since figures for energy consumption are usually not available with an hourly resolution for a whole year, the energy consumption must be calculated from typical day and year load curves with the help of a demand model. The curves must be available separately for the various energy demand sectors which one wishes to simulate. From these load curves, the energy consumption for each simulation step in each region is calculated with the help of a demand model, which can be weather-dependent . The total energy consumption is the sum of the energy consumption of the individual regions, which in turn is subdivided into the various energy consumption sectors. The simulation offers the ability to compute statistical fluctuations into the energy demand. This reflects realistic deviations from standardized daily load curves, and also offers the opportunity of studying the sensitivity of the results to fluctuations, for example due to varying consumer behavior.

Besides the modules for energy production and energy consumption named, there must also be control mechanisms in the simulation, to ensure that the energy suppliers are adjusted sensibly to one another. These control mechanisms control the adjustable energy suppliers and the consumers, if a demand management is possible in to be simulated. In each region, there is an “energy manager”, which controls the controllable energy suppliers. Interactions between the individual regions are directed by an “import-export manager”, which exchanges energy between the regions, and can make individual regions increase production within the limits of their reserve capacity.

The modular structure of the simulation allows the elements described to be combined into larger units, which can then be used repeatedly in a simulation. Thus, several wind turbines are grouped into a wind farm; such wind farms combine with other energy suppliers to form an energy supplier group. The largest units in SimRen are the “regions”, which contain all the energy suppliers and consumers of a region. These regions are also modular, and interact with one another.

10.3) Course of the simulation

SimRen calculates energy consumption and production separately for each time increment. First, the non-controllable energy demand is simulated, then the non-controllable share of the supply is calculated. Afterwards, the controllable shares of the energy supply and consumption are calculated. These calculations are performed at the regional level first, and then combined for the entire country. The production of the individual components within the regions is coordinated by the “energy manager”. The import-export manager coordinates production between the regions.

The energy consumption is simulated in SimRen by energy sector and region. Parts of the demand are oriented to the climatic conditions, such as the amount of heat needed for heating.

SimRen is capable of simulating demand management. In this case, some of the energy demand must be simulated together with the controllable energy suppliers, so as to enable the energy manager to control it, as well. This makes it possible to coordinate demand with the energy production of the fluctuating suppliers.

By means of demand management, one can reduce the demand for energy in periods of lower energy production by the fluctuating energy suppliers, thus helping to reduce the capacities that are only provided for peak-load periods.

After the uncontrollable consumers, the fluctuating electricity producers are simulated. The sets of meteorological data belonging to the sites of the respective producers are used for this.

In order to ensure sensible control of the controllable suppliers and consumers, an “energy manager” is integrated into each region. The energy manager attempts to cover the energy demand in the region from local sources as far as possible, in order to minimize transmission losses. If it is not possible to produce the energy needed, the energy manager discharges reservoirs or throttles back consumers. If that is still not enough, the energy manager notifies the “import-export manager” that there is a shortage.

All the regions are subordinate to an “import-export manager”. This exchanges power from regions with unused supply capacities or surpluses with under-supplied regions. Thus regions that cannot supply themselves sufficiently can still be supplied with electric power. The manager attempts to obtain the power from adjacent regions, so as to minimize transmission losses. If not enough power is available in total, the import-export manager requests more power from regions that are able to produce more than they consume themselves.

With this redistribution of electrical energy, it is possible to include in the balancing the transmission losses that occur during the transmission of the electricity. For this, the import-export manager needs information on the length and number of lines between the individual subregions.

10.4) The demand model

With the help of daily and annual demand curves, SimRen can compute the energy demand at any time in a year, with a 15-minute resolution, from the total annual demand. At present, a German and a Japanese demand model exist. The Japanese model is used here to explain the way in which the consumer model operates.

In the Japanese model, the consumer sectors household, industry, commerce, and services are implemented.

The goal of the consumer model is to compute the energy demand of a consumption sector and within a region, with a temporal resolution of fifteen minutes. This is necessary because demand data with such a temporal resolution for an entire year are not available for most regions and sectors.

Typical annual and daily load curves and the total annual consumption of the sectors in the regions serve as the basis for the calculation. The annual load curve should have a temporal resolution of one month, and reflect the average consumption of the sector. Daily load curves have an hourly resolution, and represent the average consumption within this hour. At least a weekday curve and a weekend curve for each season is needed for the daily load curves. The algorithm is more accurate if more daily load curves are available. For example, it is helpful to have different daily load curves for each month, and different curves for Saturdays and Sundays. Examples of annual load curves are shown in Figure 57. Examples for daily load curves are in Figure 54, Figure 55 and Figure 56.These were prepared in the ERJ research project, coordinated by the ISEP Institute.

In SimRen, normalized curves, in which the area under the curve is normalized to 12 or 24, are derived from the daily and annual load graphs in order to compute the consumption. Thus the values of the individual curves can be multiplied by one another, while preserving the shape of the individual curves. If this is then linked with the desired total annual consumption, a value for each step of the simulation is obtained, and the shape of the specified curves is retained. The load curves are then combined in such a way by the algorithm that the shape of the individual daily and annual load curves is preserved, and the integral under the consumption curve gives the total annual energy consumption.

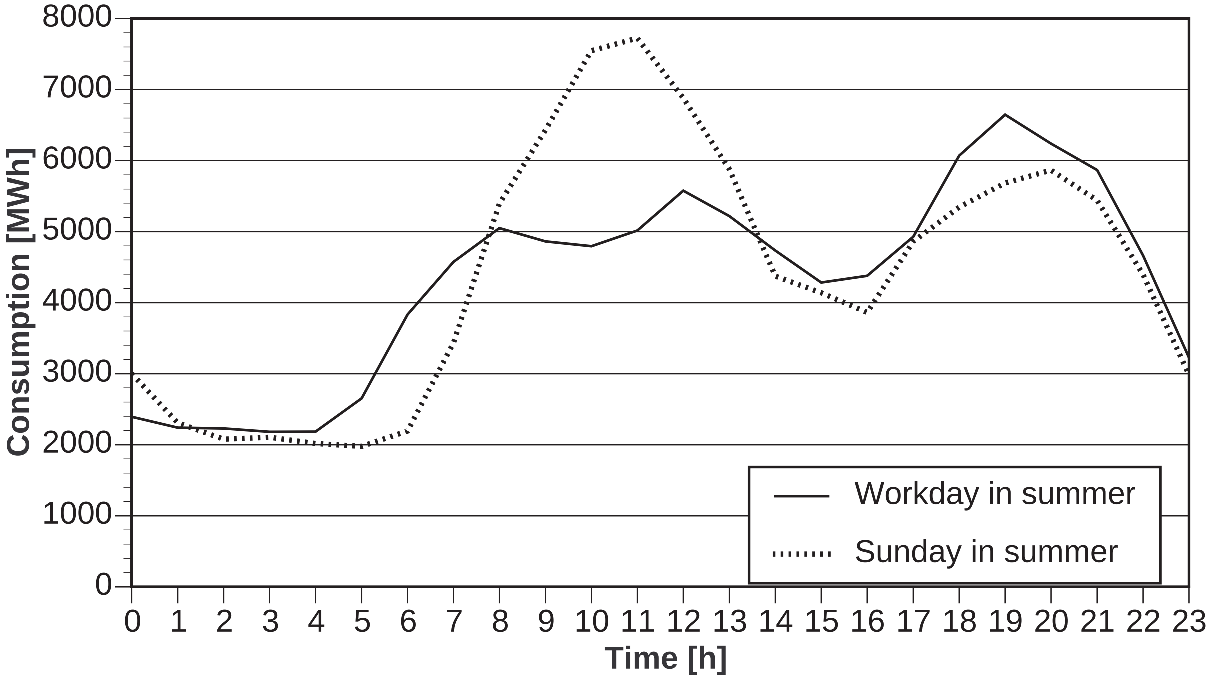

Figure 54 : Daily load curves for households in Japan in summer. Source: ISEP

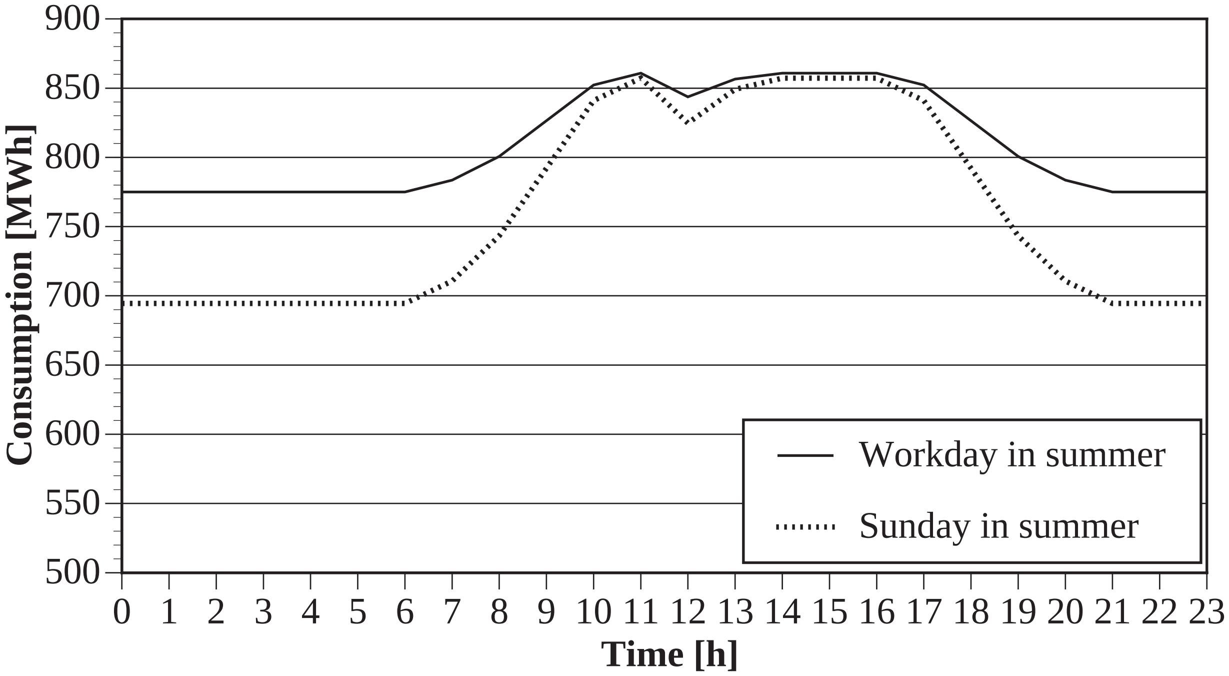

Figure 55 : Daily load curves for industry in Japan in summer. Source: ISEP

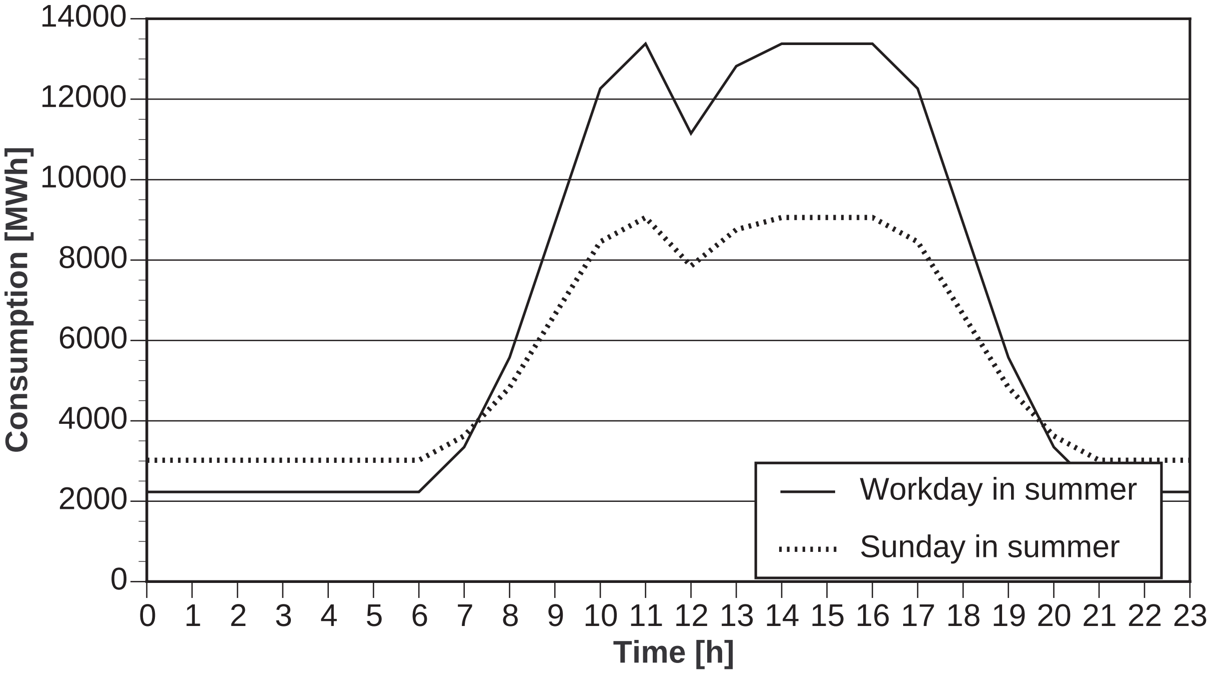

Figure 56 : Daily load curves for commerce and service sector in Japan in summer. Source: ISEP

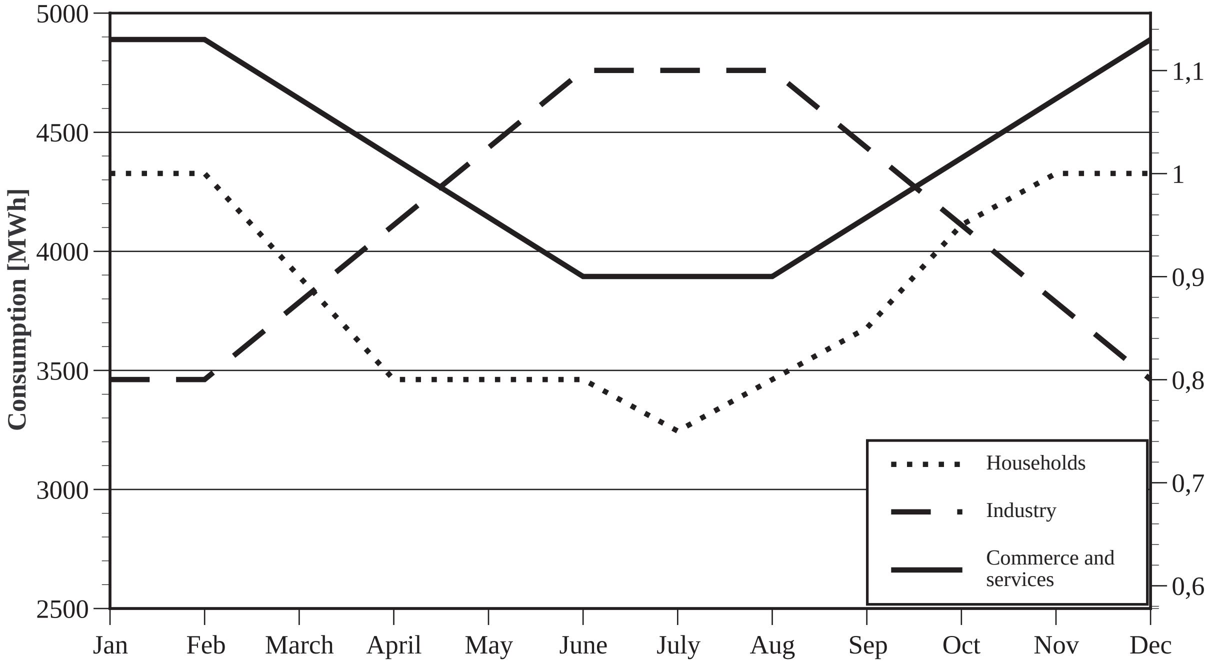

Figure 57 : Annual load curves of various energy-consumption sectors on an absolute and a normalized scale. Source: ISEP

10.4.1) The computational algorithm

In Figure 54 and the subsequent figures, one can see that there is sometimes a pronounced difference between the holiday and workday consumption. Since only the shape of the curves is preserved when they are normalized, and the absolute values are lost, the computation algorithm requires the ratio of workday to weekend power consumption. Then the differing consumption on holidays and workdays can be taken into account, by reducing the consumption on weekends by this factor.

First, the annual envelope curve, which normally corresponds to the monthly consumptions of a previous year, is converted into a normalized curve. The sum of all the values in this annual curve then equals 1. This is done by forming the mean of the individual monthly consumption figures, and then dividing each individual value by this mean (see Figure 57, "Annual load curves of various energy-consumption sectors on an absolute and a normalized scale. Source: ISEP").

Daily weighting factors for each day of the year result. It is assumed that the value for each month is reached exactly on the first of that month. After this, the daily weighting factor approaches the value for the coming month linearly. This ensures that no discontinuities occur in the resultant function. Thus one can multiple a twelfth of the desired total consumption with the respective monthly value, and obtain precisely the desired total consumption over a year. The daily envelope curves are converted into normalized curves via the same algorithm.

The power consumption on weekends is usually considerably less than during the week. Therefore, another factor is introduced for weekends and workdays. This factor is calculated by adding the number of workdays to the number of holidays, which are multiplied by the ratio of consumption.

$$[\mathrm{Holiday}] = \frac{[\mathrm{HolidayConsumption}]}{[\mathrm{WorkdayConsumption}]}$$

$$[\mathrm{Mean}] = \frac{[\mathrm{NumberOfWorkingDays}] + [\mathrm{NumberOfHolidays}] \times [\mathrm{Holiday}]}{365}$$

The workday and holiday weighting factor then amounts to:

$$[\mathrm{WorkdayWeightingFactor}] = \frac{1}{[\mathrm{Mean}]}$$

$$[\mathrm{HolidayWeightingFactor}] = \frac{[\mathrm{Holiday}]}{[\mathrm{Mean}]}$$

The consumption at a specific time of year is then:

$$P_V = [\text{DailyWeightingFactor}] \times [\text{WorkHolidayWeightingFactor}] \times [\text{HourFactor}]$$

Since the daily load curves can differ widely, and the end of an autumn curve does not necessarily fit the beginning of a winter curve, for example, discontinuities that are not realistic can occur at the transition from one day to the next. This may be the case at a change in season or the change from weekday to holiday curves, for example. Therefore, the hourly weighting factors are adjusted between 9:00 p.m. and 3:00 a.m. so that the proportion of the previous day's function declines linearly, while the proportion of the coming day's function increases. This ensures that no discontinuities occur at the change from one day to the next. The consumption for the respective time of the previous day is added to the consumption of the next day with a linear factor.

In other words:

10:00 p.m.: $\frac{1}{6}[\text{AutumnConsumption}(10pm)] + \frac{5}{6}[\text{SummerConsumption}(10pm)]$

11:00 p.m.: $\frac{2}{6}[\text{AutumConsumption}(11pm)] + \frac{4}{6}[\text{SummerConsumption}(11pm)]$

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3:00 a.m.: $\frac{5}{6}[\text{AutumConsumption}(03am)] + \frac{1}{6}[\text{SummerConsumption}(03am)]$

Figure 58 shows the difference between a change in season with and without gradual adjustment of the curves to one another. The daily load curves of the last day of summer are shown in the first 24 hours, and those of the first day of autumn in the second 24 hours. In the upper curve, the curve for the last day of summer joins directly to the curve for the first day of autumn. A discontinuity between 11 p.m. and midnight can be seen clearly. This discontinuity no longer occurs in the second curve, since here the values have been adjusted to one another. The same behavior occurs upon changing from one month to another, since the curves are based on differing daily weighting factors. Therefore, a single monthly weighting factor is not sufficient; instead, the monthly weighting factors must merge into one another smoothly.

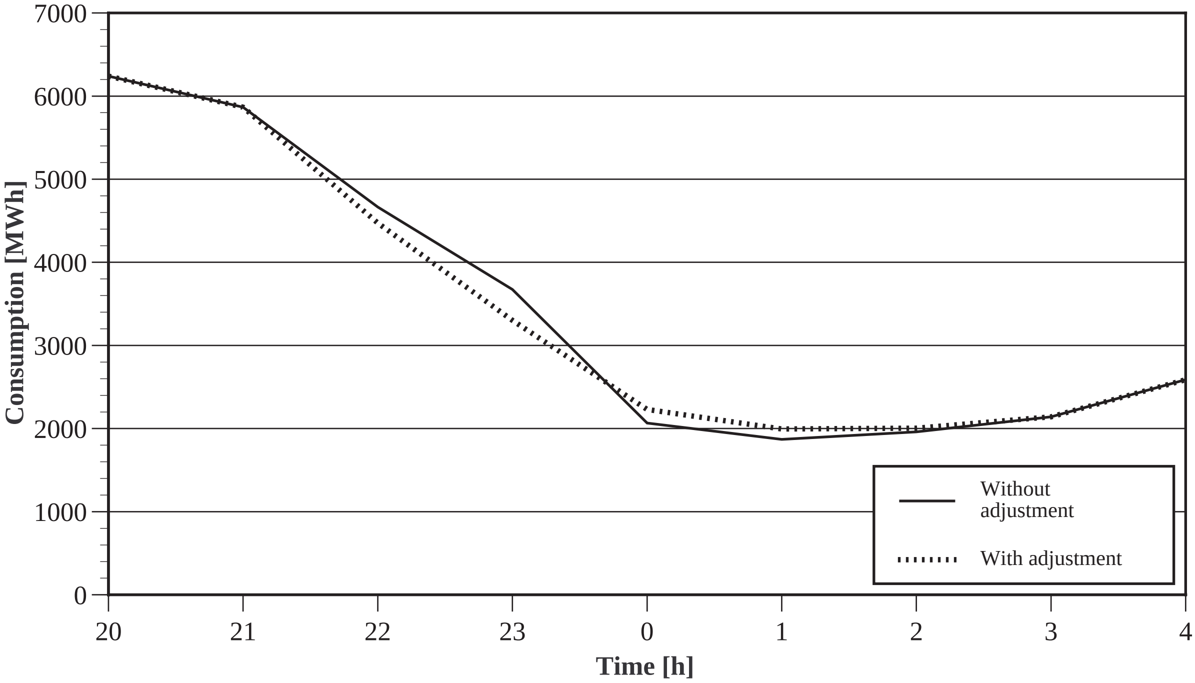


Figure 58 : Comparison of a season change with and without adjustment. Source: ISUSI

If time steps of less than an hour are simulated, the consumption values are interpolated from the two adjacent values.

The consumer module in SimRen is also capable of taking daylight savings time [summer time] into account. It simply repeats the consumption at the time the clocks are set back, and skips an hour in the load curve at the time the clocks are set forward again.

Using the consumer module described, various test runs have been performed, which showed that the total annual energy consumption specified is maintained. Furthermore, the shapes of the daily and annual curves are preserved, except for the adjustments required.

- Random fluctuations

Since SimRen is intended to ensure the security of supply of an energy supply system, the consumption module must be capable of superimposing random fluctuations on the consumption, thus allowing for the fact that consumption based on normalized curves does not reflect the real consumption that varies from day to day.

Various statistical fluctuations of the behavior pattern are possible with SimRen. The following algorithm, with which the maximum percentage change of the demand value, and the probability of achieving that value can be set, has proven itself in practice. If one does not wish to included fluctuations in the computation, the maximum excursion can simply be set to zero. The excursion of the following time step is calculated making use of the excursion of the previous step, so as not to create any discontinuities. A maximum percentage change of the excursion is defined, such as a one-percent change from one time step to the next. Then a random number between -1 and +1 is generated, and multiplied by the desired maximum excursion in percent. If the excursion in the previous step was larger than this number, the step size is deducted from the previous excursion again, giving the new excursion. Otherwise, the step size is added to obtain the new step size. This means that it is always more probable that the excursion shifts towards zero again than that it shifts away from it. This is important to keep large excursions from being maintained over considerable lengths of time.

In this algorithm, the step size is a measure of the probability of the maximum excursion actually being achieved. If a small step size is chosen, the excursion will tend to shrink towards zero again, rather than towards its maximum value.

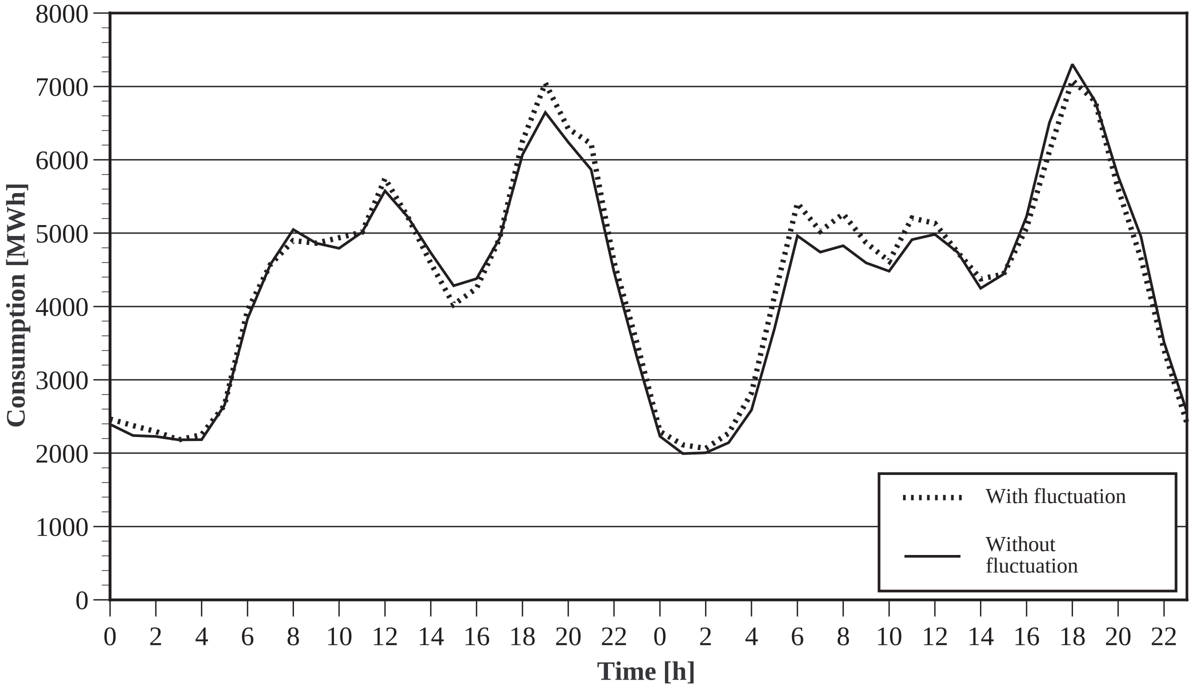
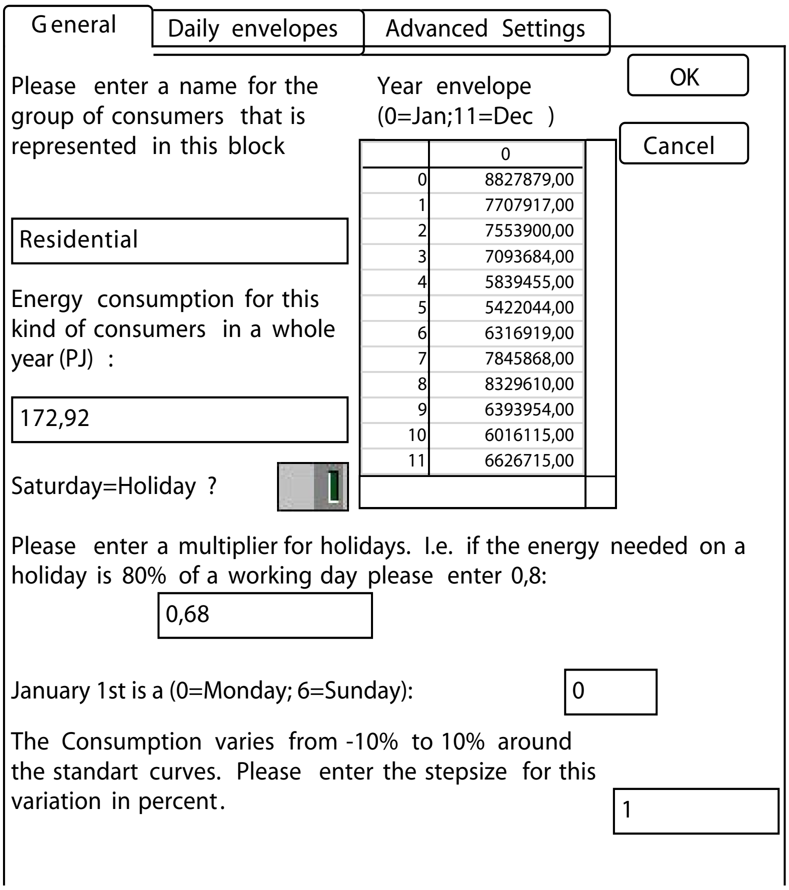


Figure 59 : Effects of random fluctuations on the curves. Source: ISUSI

Figure 59 shows the difference between a curve with and without fluctuations. Fluctuations of up to 50% of the initial value are included, and the step size is 3%. It is evident that the peak load on the first day is also shifted significantly upwards. Although the maximum possible fluctuation is 50%, values of such magnitude do not occur on those two days, since it is very improbable that the deviation would become that large. An increase of the fluctuation would need to occur for 17 time steps, which becomes more and more improbable the larger the deviation in the preceding step was.

From the static input parameters, such as the total annual energy consumption and the load curves, a dynamic energy consumption model is developed in SimRen. Tests have shown that the total annual energy consumption of the dynamic model corresponds to the static input parameter again. And the shapes of the annual and daily curves in the dynamic final result are also analogous to the input again. The random fluctuations do not change the total annual consumption substantially, either, since the fluctuations in both directions balance out. Noticeable differences only occur over shorter periods, such as a day.



Please enter a name for the group of consumers that is represented in this block

Residential

Energy consumption for this kind of consumers in a whole year (PJ) :

172,92

Saturday=Holiday ? ☑

Year envelope (0=Jan;11=Dec)

	0
0	8827879,00
1	7707917,00
2	7553900,00
3	7093684,00
4	5839455,00
5	5422044,00
6	6316919,00
7	7845868,00
8	8329610,00
9	6393954,00
10	6016115,00
11	6626715,00

Please enter a multiplier for holidays. I.e. if the energy needed on a holiday is 80% of a working day please enter 0,8:

0,68

January 1st is a (0=Monday; 6=Sunday): 0

The Consumption varies from -10% to 10% around the standart curves. Please enter the stepsize for this variation in percent.

1

Figure 60 : The input dialog of a consumer module. The total consumption, the weekend factor, and the variation are entered here. The annual load curve is also entered on this page. The daily load curves are entered on the ‘Daily envelopes’ page. Source: ISUSI

10.5) The energy supply model

The energy suppliers in SimRen can be classified in controllable and fluctuating energy suppliers. The energy production of the fluctuating energy suppliers cannot be regulated, due to their dependence on weather, irradiation, and demand. Therefore, they are simulated immediately after the unregulated energy consumers, since no control of the components is possible, and their output must be known in order to control the controllable suppliers. Intelligent control of the controllable energy suppliers is absolutely necessary for implementing a well-functioning electrical supply system, since they must produce precisely the amount of power the consumers are still lacking at any time.

Wind, solar thermal and photovoltaic facilities are fluctuating energy suppliers, since their output depends on the supply of wind or solar radiation. Apart from these obviously fluctuating electricity producers, combined-heat-and-power (CHP, or cogeneration) plants in the industrial, domestic, commercial, and services sectors are counted among the fluctuating suppliers if they are controlled according to their heat output. This classification makes sense, since the output of electric power from such power plants only depends on the demand for heat in the sectors named. The power plants produce heat for hot water and heating, and are thus oriented to the outdoor temperatures in the respective regions.

The controllable energy suppliers that have been used in SimRen are hydroelectric plants, geothermal power plants, peak power plants, and combined-heat-and-power plants that are controlled according to their electricity output. Biomass and coal-fired power plants are controllable if enough fuel is available. Otherwise, their control range is limited by the supply of fuel. Pumped-storage power plants are also controllable, apart from their dependence on the level of the reservoirs. The output of the hydroelectric plants depends on the water level of the rivers on which they lie, but can be adjusted freely below this upper limit.

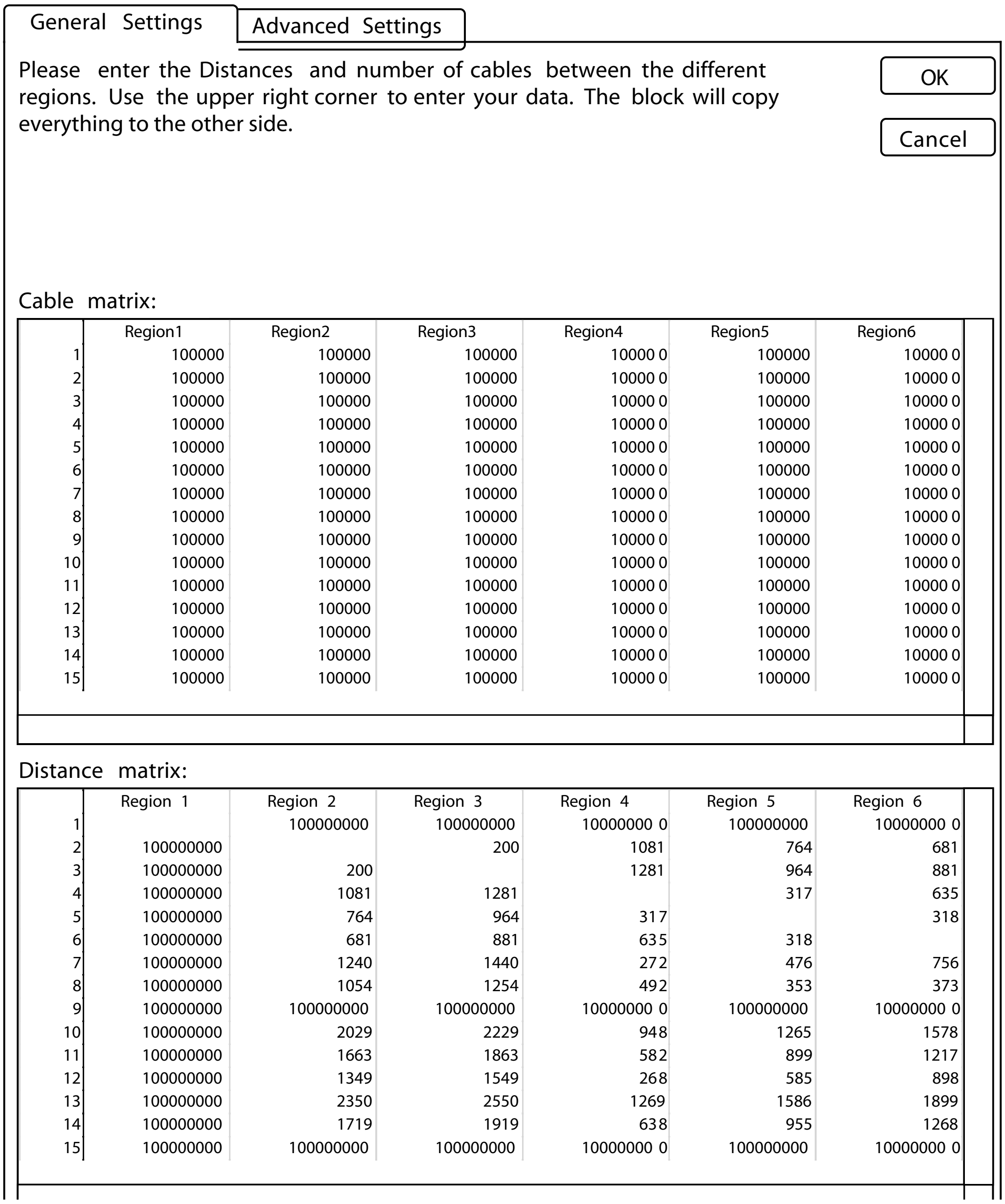
The energy manager controls the energy output of the controllable energy suppliers and the energy consumption of the controllable consumers within a region. The control logic can be adjusted easily. Apart from the non-controllable energy demand and the non-controllable energy consumption within a subregion, it also depends on the demand from the import-export manager. Thus the import-export manager is able to request energy from or provide energy to an energy manager within a region.

The feedback control that proved to make sense for the Japanese energy system is explained below. In ERJ, the combined-heat-and-power facilities are engines and steam turbines that supply industrial plants with the necessary process heat. Two-thirds of this capacity runs constantly all day long, while the remaining third can be adjusted to the demand for electricity.

This mode of operation is possible because the hot water and steam produced by the plants can be stored well, and does not necessarily have to be produced exactly at the moment it is needed.

First, the energy manager starts up the CHP units in the industrial plants, and attempts to meet the energy demand with them. Next, geothermal power plants are brought on line. Since the power available from the hydroelectric plants depends on the water level of the rivers, and is thus subject to limitations, those power plants are started up last.

It often happens that individual subregions are not able to provide themselves with an autonomous supply of energy, while in others, there is surplus production or unused capacity available. Balancing out these production deficits and surpluses at a supraregional level is the responsibility of the import-export manager, which is superior to all the regions and coordinates them.



Please enter the Distances and number of cables between the different regions. Use the upper right corner to enter your data. The block will copy everything to the other side.

Cable matrix:

	Region1	Region2	Region3	Region4	Region5	Region6
1	100000	100000	100000	10000 0	100000	10000 0
2	100000	100000	100000	10000 0	100000	10000 0
3	100000	100000	100000	10000 0	100000	10000 0
4	100000	100000	100000	10000 0	100000	10000 0
5	100000	100000	100000	10000 0	100000	10000 0
6	100000	100000	100000	10000 0	100000	10000 0
7	100000	100000	100000	10000 0	100000	10000 0
8	100000	100000	100000	10000 0	100000	10000 0
9	100000	100000	100000	10000 0	100000	10000 0
10	100000	100000	100000	10000 0	100000	10000 0
11	100000	100000	100000	10000 0	100000	10000 0
12	100000	100000	100000	10000 0	100000	10000 0
13	100000	100000	100000	10000 0	100000	10000 0
14	100000	100000	100000	10000 0	100000	10000 0
15	100000	100000	100000	10000 0	100000	10000 0

Distance matrix:

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
1		100000000	100000000	10000000 0	100000000	10000000 0
2	100000000		200	1081	764	681
3	100000000	200		1281	964	881
4	100000000	1081	1281		317	635
5	100000000	764	964	317		318
6	100000000	681	881	635	318	
7	100000000	1240	1440	272	476	756
8	100000000	1054	1254	492	353	373
9	100000000	100000000	100000000	10000000 0	100000000	10000000 0
10	100000000	2029	2229	948	1265	1578
11	100000000	1663	1863	582	899	1217
12	100000000	1349	1549	268	585	898
13	100000000	2350	2550	1269	1586	1899
14	100000000	1719	1919	638	955	1268
15	100000000	100000000	100000000	10000000 0	100000000	10000000 0

Figure 61 : Dialog of the import-export manager. The lengths and numbers of lines connecting the subregions can be entered here. The import-export manager calculates an energy distribution matrix with the minimum transmission losses from this information. Source: ISUSI

First, the import-export manager distributes the surpluses from individual regions (if there are any) to the undersupplied regions, until all the surplus power has been used up, or all regions have been supplied. It uses the shortest possible distances for this distribution. The energy losses can be estimated by the import-export manager, and included in the balance as energy consumption. The transmission losses can be calculated as a percentage of the total energy produced, or from the information on line lengths in the import-export manager.

The import-export manager is able to start up the peak power plants and to empty the reservoirs if the potential total output is not sufficient to cover the total demand. Various control algorithms can be implemented for this purpose.

For the ERJ study, it proved to make sense to start up 1 GW of the peak power plants' capacity first, if there is a risk of under-supply. Next, the pumped-storage reservoirs can be used to produce energy; and if this is still not enough, there is another 2 GW of peak power plants' capacity available to meet the demand for power. In addition, the import-export manager can order the energy managers in the individual regions to produce more power than they need, in order to cover the demand for energy in other regions. This ensures that the installed power plants are utilized optimally. The strategy described proved to be a good solution for the Japanese energy system; in combination with a sensible distribution of the facilities, it allows the demand for energy to be met with the minimum of installed capacity. However, this algorithm can also be adjusted easily by means of a small alteration in the import-export manager. The combination of peak power plants and pumped-storage reservoirs results in the pumped-storage reservoirs usually still containing an emergency reserve if power plants fail unexpectedly, and not too much hydrogen is burned in the peak power plants.

10.5.1) Simulation of the energy supply components

1. Computation of the energy output of photovoltaic systems:

In order to calculate the power output of a photovoltaic array, detailed data on the solar irradiance are essential. The irradiance is categorized as "direct" and "diffuse" radiation. Direct radiation reaches the Earth's surface directly from the Sun, while diffuse radiation is scattered by clouds or dust particles. Since weather stations mainly measure "global" (= direct + diffuse) radiation, the irradiation must be divided up. This splitting can be done by means of an algorithm that requires the sun's current position in the sky. Once the position of the sun has been calculated, the split between diffuse and direct radiation can be calculated by the following equations[107]:

$$k_T = \frac{E_{g,\,hor}}{E_0}$$

$$E_{diff,\,hor} = E_{G,\,hor}\,(1.020 - 0.254\,k_T + 0.0123\,\sin\partial_s)\ \text{for}\ k_T \leq 0,3$$

---

[107] Quaschning (1999)

$$E_{diff,\ hor} = E_{G,\ hor}(1.400 - 1.749k_T + 0.177\sin \partial_s) \text{ for } 0,3 < k_T < 0,78$$

$$E_{diff,\ hor} = E_{G,\ hor}(0.486\ k_T + 0.182 \sin \partial_s) \text{ for } k_T \geq 0,78$$

Eg,hor is the global radiation impinging on a horizontal plane, E0 the solar constant, gs the position of the sun, and Eg,diff the diffuse radiation impinging on a horizontal plane.

Since the irradiance of a horizontal plane differs from that of an inclined plane, the irradiance must be converted. This conversion can be done using Lin and Jordan’s equation.

$$E_{g,\ I} = R \cdot E_{dir,\ hor} + \left(\frac{1}{2}(1 + \cos n)\right) \cdot E_{dir,\ hor} + p \cdot E_{G,hor}$$

E = Irradiance

p = Reflection coefficient (must be estimated)

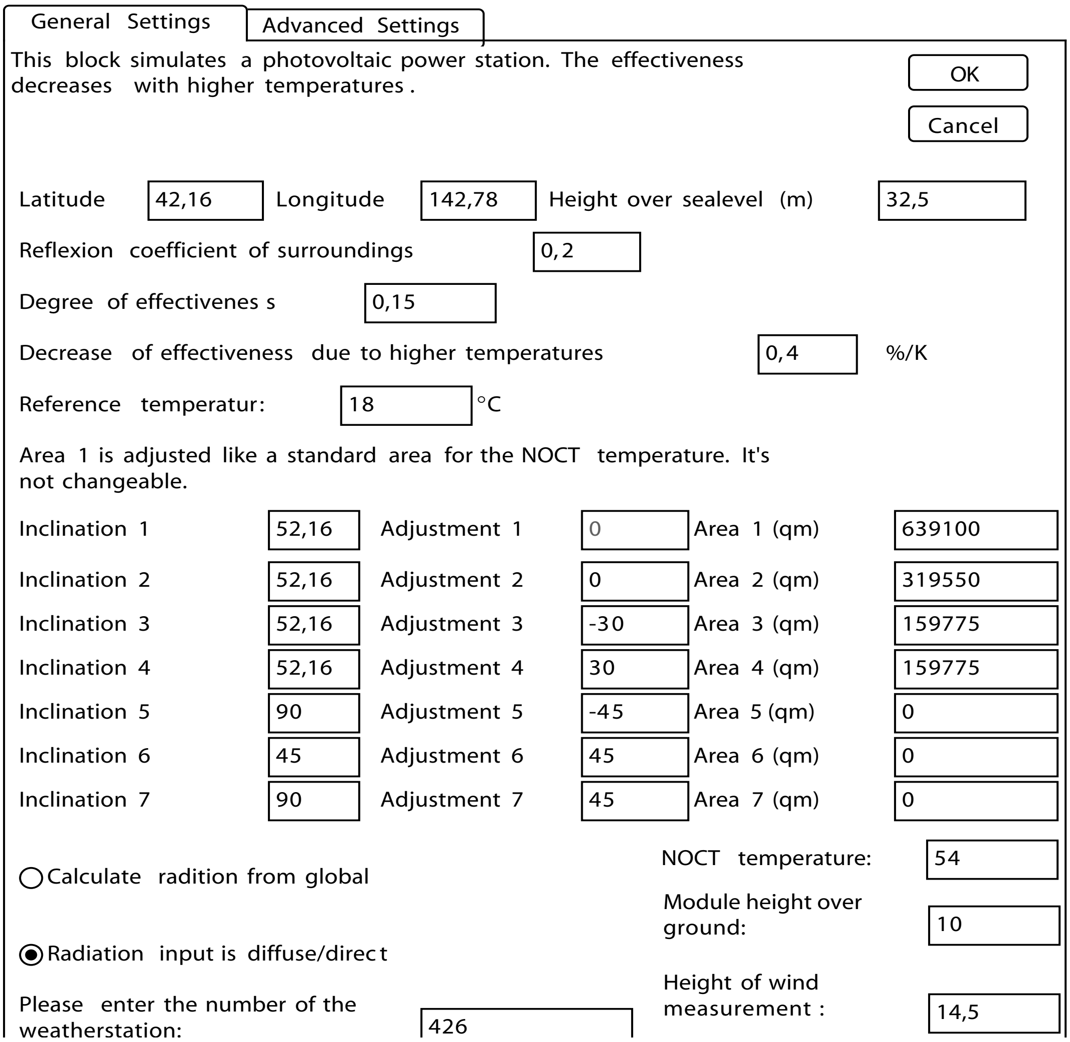
n = Angle of inclination

R = Ratio of the direct radiation onto an inclined and a horizontal plane

The temperature dependency of the efficiency has been taken into account using a model by Fuentes. This model calculates the module temperature from the irradiance and the wind speed.<108>

And it is also possible to simulate elevated solar arrays that shade one another when the sun is in certain positions. For calculating them, flat roofs with a width of 10 m, and solar arrays 1 m long spaced 2 m apart were assumed. Shading losses amount to about 1.5% compared to a simulation that does not take shading into account.

108.Fuentes (1987)



This block simulates a photovoltaic power station. The effectiveness decreases with higher temperatures .

Latitude 42,16 Longitude 142,78 Height over sealevel (m) 32,5

Reflexion coefficient of surroundings 0,2

Degree of effectivenes s 0,15

Decrease of effectiveness due to higher temperatures 0,4 %/K

Reference temperatur: 18 °C

Area 1 is adjusted like a standard area for the NOCT temperature. It's not changeable.

Inclination 1	52,16	Adjustment 1	0	Area 1 (qm)	639100
Inclination 2	52,16	Adjustment 2	0	Area 2 (qm)	319550
Inclination 3	52,16	Adjustment 3	-30	Area 3 (qm)	159775
Inclination 4	52,16	Adjustment 4	30	Area 4 (qm)	159775
Inclination 5	90	Adjustment 5	-45	Area 5 (qm)	0
Inclination 6	45	Adjustment 6	45	Area 6 (qm)	0
Inclination 7	90	Adjustment 7	45	Area 7 (qm)	0

○ Calculate radition from global

● Radiation input is diffuse/direct

Please enter the number of the weatherstation: 426

NOCT temperature: 54

Module height over ground: 10

Height of wind measurement : 14,5

Figure 62 : Dialog for a photovoltaic module. Various surfaces with differing alignments, that are all connected to the same weather station, can be entered here. In addition, the module requires information on the position of the module and its efficiency. More than one angle of inclination and declination (“Inclination” and “Adjustment”) with solar arrays of different sizes can be set. The setting “Radiation input is diffuse/direct” means that the meteorological data are available divided into diffuse and direct radiation, in contrast to “Calculate radiation from global”, where these data must be computed from the global irradiance. The “number of the weatherstation” identifies the set of meteorological data pertaining to the module. Source: ISUSI

2. Calculation of solar-thermal heat output:

The heat produced by solar thermal collectors can also be calculated with SimRen. It is calculated using the same equations as for the photovoltaic output, but without temperature dependence of the efficiency. SimRen computes the diffuse and direct radiation impinging on an inclined surface, and multiplies this with the efficiency of the solar thermal system.

In ERJ, 50% was assumed as the efficiency for temperatures up to 50°C. Such temperatures are needed in all consumer sectors while higher temperatures are often needed in industry. So an efficiency of 25% has been assumed for temperatures up to 150°C. These efficiencies are overall system efficiencies. Only storage losses have to be accounted for separately. In ERJ, the storage losses were calculated after the simulation, from the duration of storage and a loss factor. The dialog for this module offers the same possible inputs as for a photovoltaic module, except that no temperature-dependent efficiency can be specified.

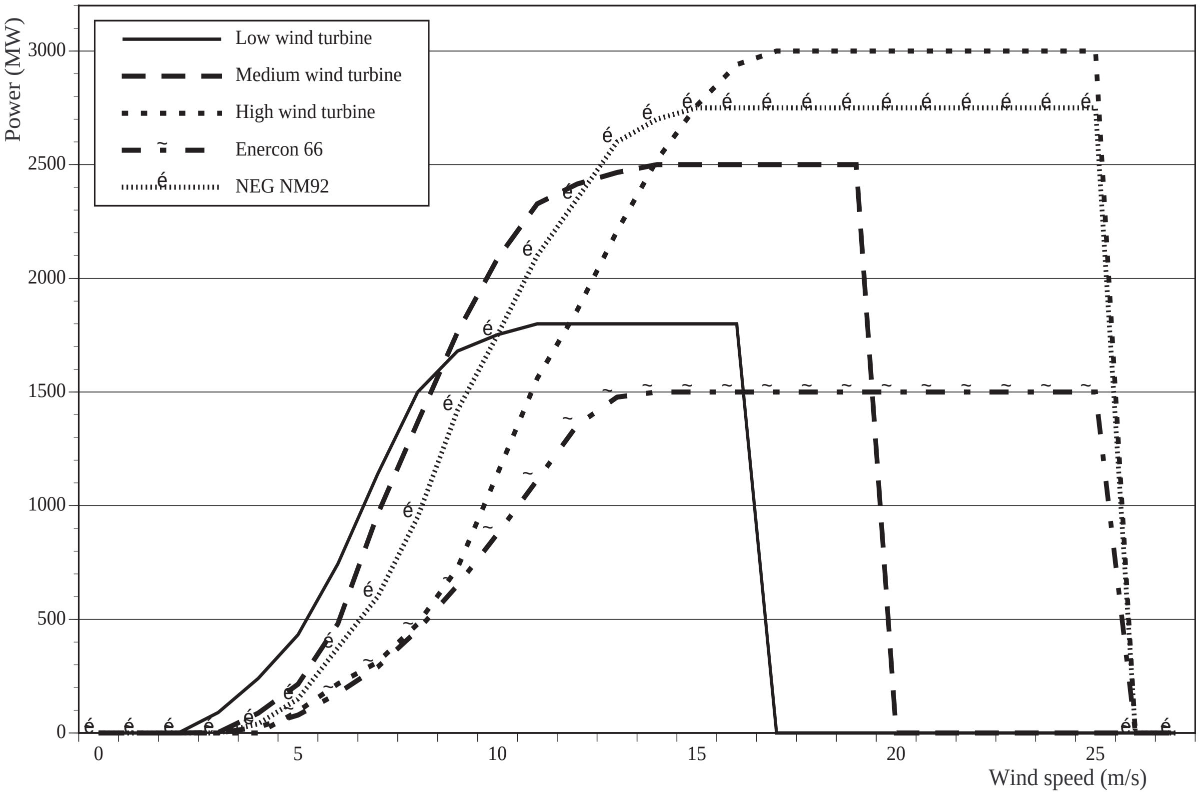
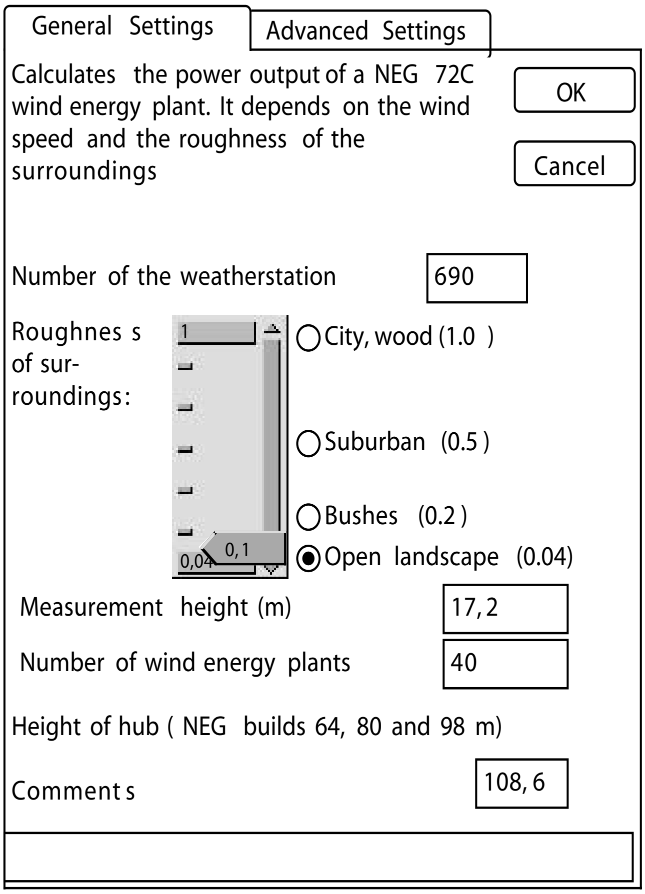


Figure 63 : Typical output curves of wind turbines. Source: ISUSI

3. Calculation of wind energy output:

The simulation of the power output of aerogenerators is based essentially on typical output curves for wind turbines. Any number of different kinds of wind turbine can be integrated into SimRen. At present, the SimRen libraries contain wind turbines from Enercon, Tacke, NEG Micon, and artificial wind turbines, whose performance is oriented to the output curves of various units. It is possible to integrate additional wind turbines. Due to the modular construction of the software, wind farms can be combined from various models of wind turbines.



Calculates the power output of a NEG 72C wind energy plant. It depends on the wind speed and the roughness of the surroundings

Number of the weatherstation: 690

Roughness of surroundings:
○ City, wood (1.0)
○ Suburban (0.5)
○ Bushes (0.2)
● Open landscape (0.04)

Measurement height (m): 17,2

Number of wind energy plants: 40

Height of hub (NEG builds 64, 80 and 98 m): 108, 6

Comments

Figure 64 : Typical dialog for a group of wind turbines. The number of wind turbines, the height of their hubs, and the roughness of the surroundings can be entered. Some information from the adjacent weather station is also required. Thus each wind turbine can have its own set of meteorological data assigned to it, which is given in the field “Number of the weatherstation”. Source: ISUSI

Using the output curves in Figure 63, it is easy to determine the output of the wind turbines, as long as the wind speed at hub height is known. The weather stations usually do not measure the wind speed at hub height, therefore the wind speed must be converted to hub height, using the logarithmic height equation<109>.

$$v(h_2) = v(h_1) \cdot \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)}$$

where h1,2 is the respective height, v1,2 the speeds, and z0 is the roughness length.

---

[109] Quaschning (1999)

The roughness length in this equation categorizes the various types of landscape. For the conversion to hub height, a roughness length of 0.1 metres has been used. This corresponds to a landscape with bushes.

Since sometimes no meteorological data from offshore weather stations are available, the wind-turbine module is capable of computing the wind speed at sea from the wind speed on land. As measurements in Germany and Denmark confirm, the wind speed at sea is about 33% higher than on land. In order to compute the wind speed of the offshore installations at hub height, SimRen therefore first calculates the wind speed at hub height on land, and then multiplies this by 1.33. Then the achievable output can be calculated using the output curve. The multiplication factor can be adjusted, if necessary.

4. Calculation for the heat-oriented combined-heat-and-power plants

The electrical energy generated by combined-heat-and-power plants in the household, commercial, and services sectors is oriented to the outdoor temperature in the respective regions and the demand for hot water. It is assumed that hot water can be stored all day, and that the demand is thus constant the whole day. Therefore, only the energy demand for heating systems fluctuates. The control of heating systems can be adjusted to the respective needs in SimRen.

In the ERJ study, the CHP plant begins to heat the houses up to a particular target temperature when the outdoor temperature falls below a particular value. These starting and target temperatures differ for daytime and nighttime. The values for the starting and target temperature and the times of day can be set as desired in the component.

The energy required to heat up the households and commercial and service buildings by 1°C must be defined beforehand. In addition, a thermal and an electrical efficiency must be assumed, in order to calculate the electrical energy. In the Japanese energy supply model, the electrical efficiency is 30%, and the thermal efficiency is 50% in SimRen. So the electrical energy can be calculated by the following equation:

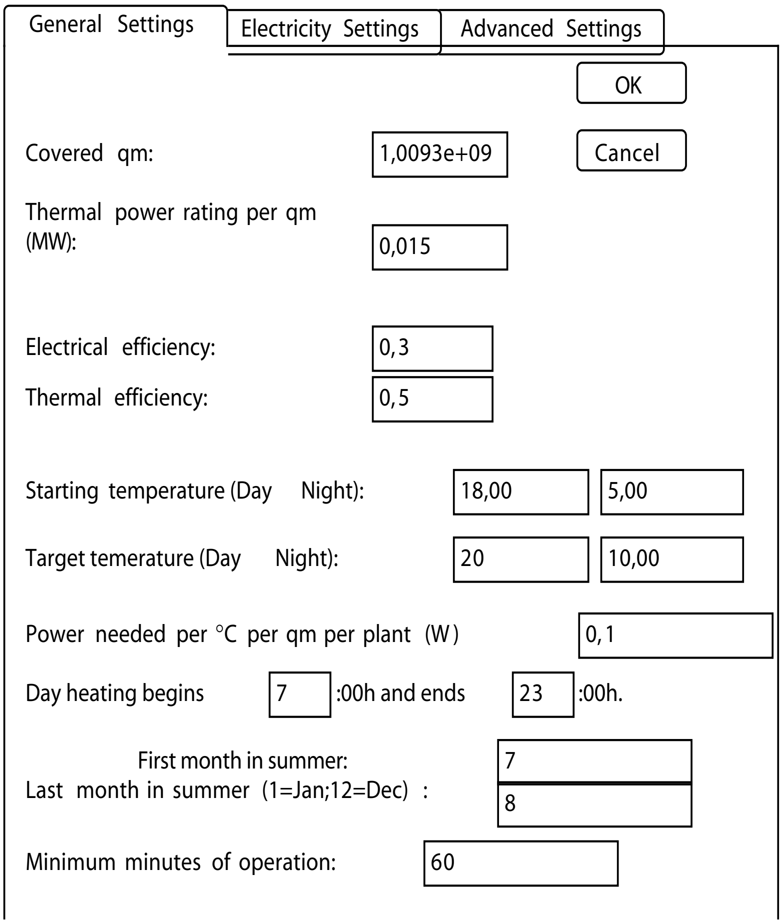
$$\Delta T = T_{target} - T_{outsi}$$

$$P_{out} = \frac{\Delta T \cdot P_C \cdot \eta_{el}}{\eta_{th}}$$

T_{target} = target temperature, $T_{outside}$ = outdoor temperature, P_{out} = power output,

$P_{\circ C}$ = energy requirement per °C, h_{th} = thermal efficiency, h_{el} = electrical efficiency

In the ERJ study, the units heat houses in the daytime as soon as the temperature falls below 18°C, up to a temperature of 20°C. The heating keeps running for at least an hour, in order to prevent constant switching on and off due to fluctuating temperatures. At night, the target temperature is 15°C, and the starting temperature 10°C; but since not all rooms are heated at night, an average starting temperature of 5°C and a target temperature for the whole house of 10°C was assumed. In other words, the 5°C and 10°C nighttime temperatures are an average temperature for the rooms in the house, not all of which are heated at night. The reduction to nighttime levels begins at 11 p.m. and ends at 7 a.m. In the ERJ study, only one reference temperature for cogeneration electricity production was assumed per region. Using more than one is possible in principle, and would make control easier.



Covered qm: 1,0093e+09

Thermal power rating per qm (MW): 0,015

Electrical efficiency: 0,3

Thermal efficiency: 0,5

Starting temperature (Day Night): 18,00 5,00

Target temerature (Day Night): 20 10,00

Power needed per °C per qm per plant (W) 0,1

Day heating begins 7 :00h and ends 23 :00h.

First month in summer: 7

Last month in summer (1=Jan;12=Dec) : 8

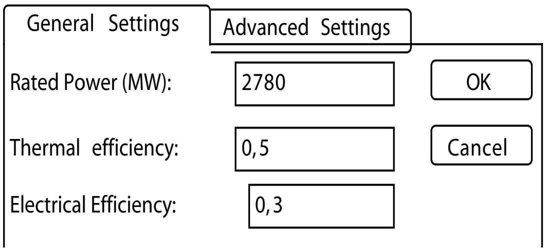
Minimum minutes of operation: 60

Figure 65 : Dialog for CHP plant in the household and industrial sectors. The times of day and target temperatures for daytime and nighttime heating can be entered here, for example (“Day heating begins ... and ends ...”, “Starting temperature”, “Target temperature”), as well as the thermal and electrical efficiency. What rated capacity per square metre is installed is entered in “thermal power rating per qm”. This value, multiplied by the “Covered qm”, gives the total rated capacity of the CHP plant module. The field “Minimum minutes of operation” can be used to specify the shortest time the installation will run after being switched on, in order to avoid constant switching on and off. This block does not require any information on the set of meteorological data, since the temperatures are passed on to the CHP plant module from a separate meteorological data module. Source: ISUSI

5. Calculation for the electricity-oriented combined-heat-and-power plants

The electricity-oriented combined-heat-and-power plants are installed with a particular capacity, and can be run up to and down from this capacity at will. In SimRen, internal-combustion engines are used to generate low-temperature heat, and steam turbines to generate high-temperature heat.

In the ERJ study, these power plants were only employed in the industrial sector, since industrial plants are usually capable of storing the heat they produced for a short time, and have a high demand for electricity in addition to the demand for heat. It was assumed that control of electricity generation in the industrial plants was performed by a variable tariff for the electricity fed into the grid. The respective electricity price must then be communicated to the industrial plants via a data network. (For further details, see the consumer model.) The efficiencies in the ERJ study are 50% thermal efficiency and 30% electrical efficiency, just like the CHP plants in the household sector and commercial and services sector.



Rated Power (MW): 2780

Thermal efficiency: 0,5

Electrical Efficiency: 0,3

Figure 66 : Dialog for CHP plants in industry. Here, the rated capacity and thermal and electrical efficiencies can be specified. Nothing more is needed to calculate the output. Source: ISUSI

6. Hydroelectric plants

Hydroelectric plants are initialized with a certain maximum output, which depends on the turbines installed. However, they cannot produce this amount of energy at all times, since the power output depends on the water level in the river on which they lie. In order to allow for this, the hydroelectric-plant module in SimRen is provided with a monthly fluctuation curve. This curve indicates what proportion of the installed capacity can be utilized in the respective month. If such curves are not available, as in the ERJ study, they can be computed from the flow rates in large rivers of the region. In the ERJ study, the mean of the flow rate was calculated, and it was assumed that the power plants are designed for this flow, in other words, that they can achieve their rated output at an average flow. If the flow is below average, it was assumed that the ratio of the flow in that month to the average flow is equal to the ratio of the output achievable to the rated capacity.

$$P_{max} = P_{Nenn} \text{ for } \hat{m}_{mom} \geq \hat{m}_{\varnothing}$$

$$\frac{P_{max}}{P_{Nenn}} = \frac{\hat{m}_{mom}}{\hat{m}_{\varnothing}} \quad \text{for } \hat{m}_{mom} < \hat{m}_{\varnothing}$$

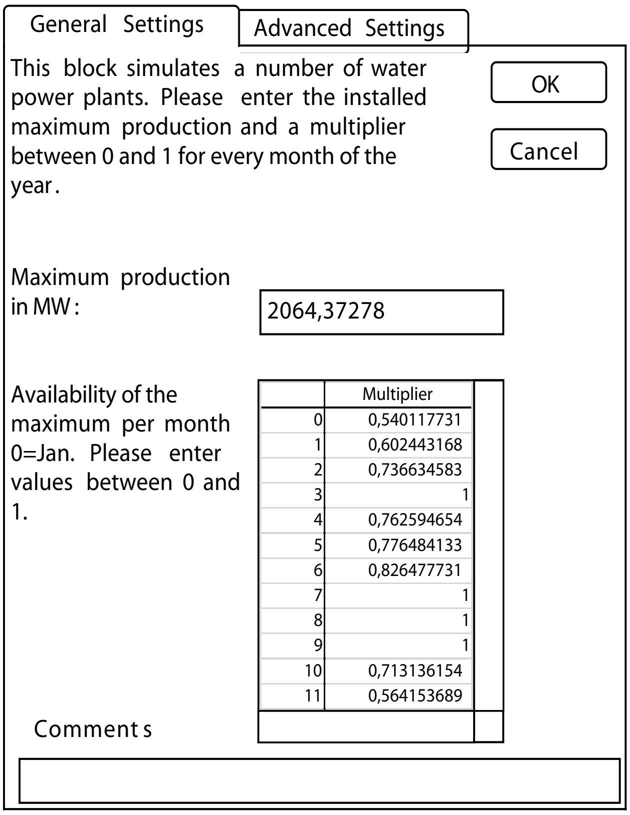
P_{max} = Maximum achievable output in the month being calculated

P_{Nenn} = Installed capacity

$\hat{m}_{mom}$ = Flow rate in the month being calculated

$\hat{m}_{\varnothing}$ = Average flow rate

Maximum power output of hydroelectric plants in the ERJ model for the Kanto region shows the proportion of the installed capacity of the hydroelectric plants that can be utilized each month, due to the flow rates in the Kanto region according to the ERJ simulation.



This block simulates a number of water power plants. Please enter the installed maximum production and a multiplier between 0 and 1 for every month of the year.

Maximum production in MW: 2064,37278

Availability of the maximum per month 0=Jan. Please enter values between 0 and 1.

	Multiplier
0	0,540117731
1	0,602443168
2	0,736634583
3	1
4	0,762594654
5	0,776484133
6	0,826477731
7	1
8	1
9	1
10	0,713136154
11	0,564153689

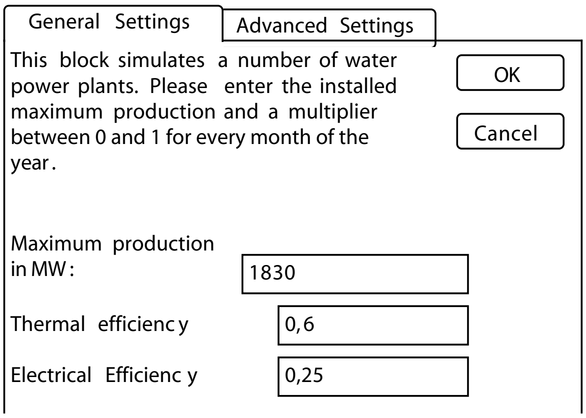
Figure 67 : Dialog for a hydroelectric plant. In addition to the rated capacity, the envelope curve for maximum energy output can be specified. Source: ISUSI

In the ERJ study, it was assumed that the output of the entire installed capacity can continue to be generated if the flow rate is greater than the annual average. If there is less water in the rivers than the annual average, the proportion of the electricity that can be generated is less to the same extent that the flow rate lies below the average. Examples for water power curves are in the Appendix.

7. Geothermal power plants

The geothermal power plants are able to produce energy up to their rated capacity. As for the hydroelectric plants, an annual curve can also be filed for the geothermal power plants.

In SimRen, it has been assumed that the achievable output of the geothermal power plants does not vary over the course of the year. The output achievable can be set freely up to the installed capacity.



This block simulates a number of water power plants. Please enter the installed maximum production and a multiplier between 0 and 1 for every month of the year.

Maximum production in MW: 1830

Thermal efficiency 0,6

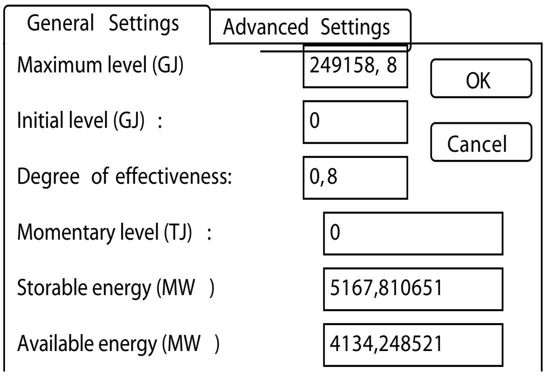
Electrical Efficiency 0,25

Figure 68 : Dialog for a geothermal power plant. Input of rated capacity and the thermal and electrical efficiencies. Source: ISUSI

8. Pumped-storage power plants

Pumped-storage power plants can store energy by converting it into the potential energy of water and storing the latter in a reservoir. This water can then be used later to drive a turbine, thus generating electrical energy again. During these conversion processes, energy losses occur, which are specified beforehand.

In the ERJ study, the energy loss per conversion was about 10.5%, resulting in a total loss of 20%. In other words, when the energy is stored, 10.5% of the energy to be stored is lost as a storage loss, and the same proportion is lost again when the reservoir is discharged due to the efficiency of the turbines and similar aspects.



Maximum level (GJ) 249158, 8

Initial level (GJ) : 0

Degree of effectiveness: 0,8

Momentary level (TJ) : 0

Storable energy (MW) 5167,810651

Available energy (MW) 4134,248521

Figure 69 : Dialog for a pumped-storage power plant. The input parameters are the maximum level, the level at the start of the simulation run, and the efficiency. In addition, the maximum storable and available capacities can be specified. The momentary level is an output parameter. Source: ISUSI

9. Conventional power plants

SimRen is capable of simulating conventional combustion power plants. Such power plants can be fueled with coal or biomass. These power plants must be connected to a fuel store, where information is stored on how much fuel is available per simulation step. The modules are initialized with a rated capacity and the amount of fuel that is consumed for that output. If enough fuel is available, they are able to produce outputs that are less than or equal to their rated capacity. If not enough fuel is on hand, the maximum output achievable is proportional to the supply of fuel. The conventional power plants use the same module in principle as the electricity-oriented combined-heat-and-power plants. Therefore, the dialog offers the same possible inputs.

10. Peak power plants

In SimRen, the peak power plants are fuel cells or steam turbines. The energy outputs of the power plants can be adjusted freely up to their rated capacity, as long as fuel is available. The efficiency of the electricity generation can be selected freely. peak power plants do not have a dialog screen of their own, since they are simulated in the import-export manager.

10.6) Results

The SimRen simulation generates several files in a simulation run, which contain all the information on the run. All this information is stored in a directory that contains the date, time, and name of the simulation run. This directory contains, divided up by regions, one file for each block in the simulation. These files contain the initialization data of the block, such as the number of wind turbine units belonging to a particular set of meteorological data, or the alignments of the solar-cell surfaces in a photovoltaic module.

A results directory is also created, containing the result data for each region and an aggregate file for all regions. The date and time of day of the time step are filed in this file for each time step. It contains the solar radiation, wind, and temperature data from a representative weather station from the region. In addition, the energy output data for the individual technologies, and the energy consumption of technologies that store energy or convert it into fuels, are printed to the file. So it contains the average output for each time step in megawatts for wind turbines and similar energy producers. The amounts stored and discharged and the available levels of reservoirs are filed. For units that produce hydrogen from electricity, the average power input in megawatts for each time step is stated. The file also contains the mean output and input per time step.

Besides these files, the simulation environment also creates another file that also stores all the results. When the simulation is reloaded, this file is also loaded. So when one loads the simulation, all the data of the last simulation run are accessible again. In the simulation, these data can also be analysed with their own block, and a desired printout can be generated. For example, the results for one region can be displayed, or the energies produced by different technologies on particular weekdays or at particular times of day.

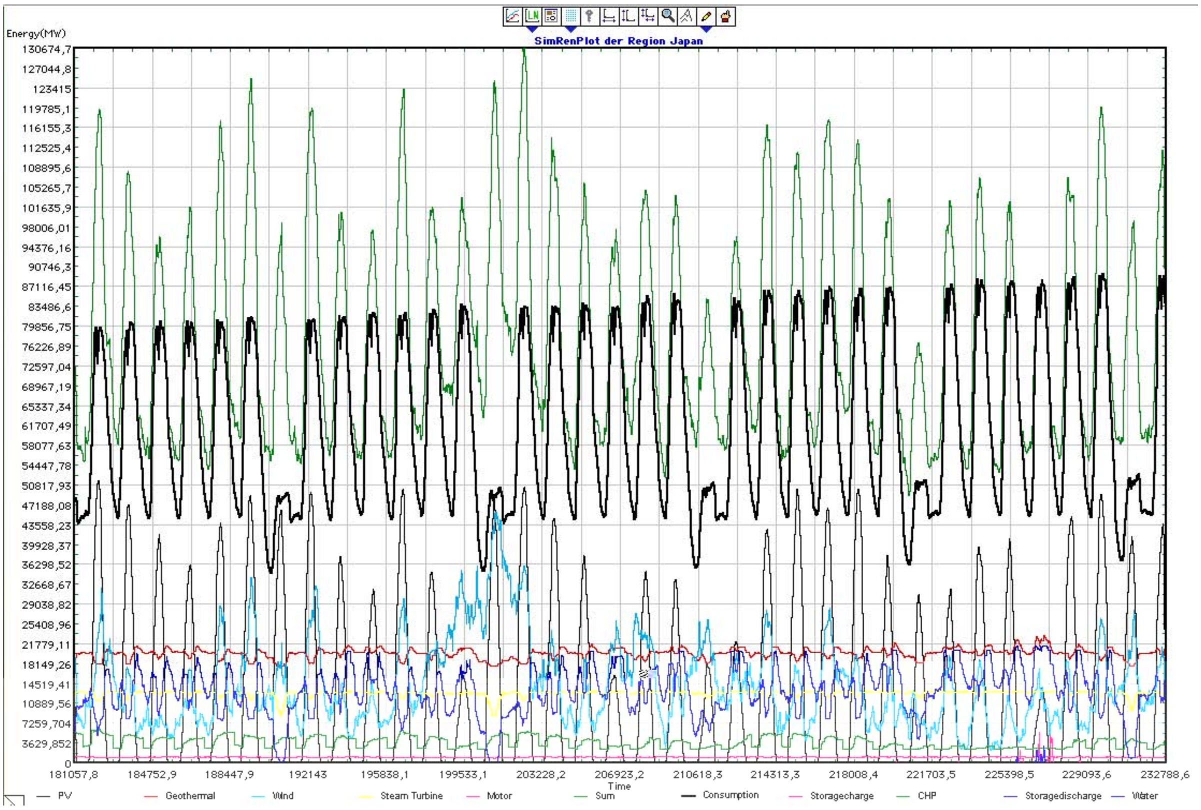


Figure 70 : Representation of a selection of the results of SimRen within the simulation environment. Source: ISUSI

10.7) Tests of the modules

For each of the energy supply and consumption modules described above, a test system has been set up for checking the computational algorithms and the results[110].

The SimRen simulation was developed with the help of the simulation environment Extend® , which provides its own programming language. A standard simulation environment was chosen in order to minimize the possible sources of error from programming.

110.Spangardt (1999).

The modules in SimRen are simple input-output modules, which can be tested well independently of the rest of the SimRen model. The photovoltaic block, for example, computes the amount of electricity generated as an output from meteorological data as an input.

In the photovoltaic module, the most complicated one, the correct calculation of the sun's position and the conversion of solar radiation onto solar-cell surfaces was tested by comparing 'manually calculated' and simulated values. The temperature-dependent reduction in efficiency is also taken into account according to the cell temperature determined. By comparison with the cell temperatures measured by ISET, the simulated cell temperatures show a very good approximation to reality <111>. Furthermore, the shading calculation for elevated modules and the time shift of the radiation data were checked. In conclusion, time series of the power output from photovoltaic arrays with various erection geometries as measured by ISET were compared to simulated time series. Reflected radiation was not taken into account in the simulation. A satisfactory to good agreement of the time series was found.

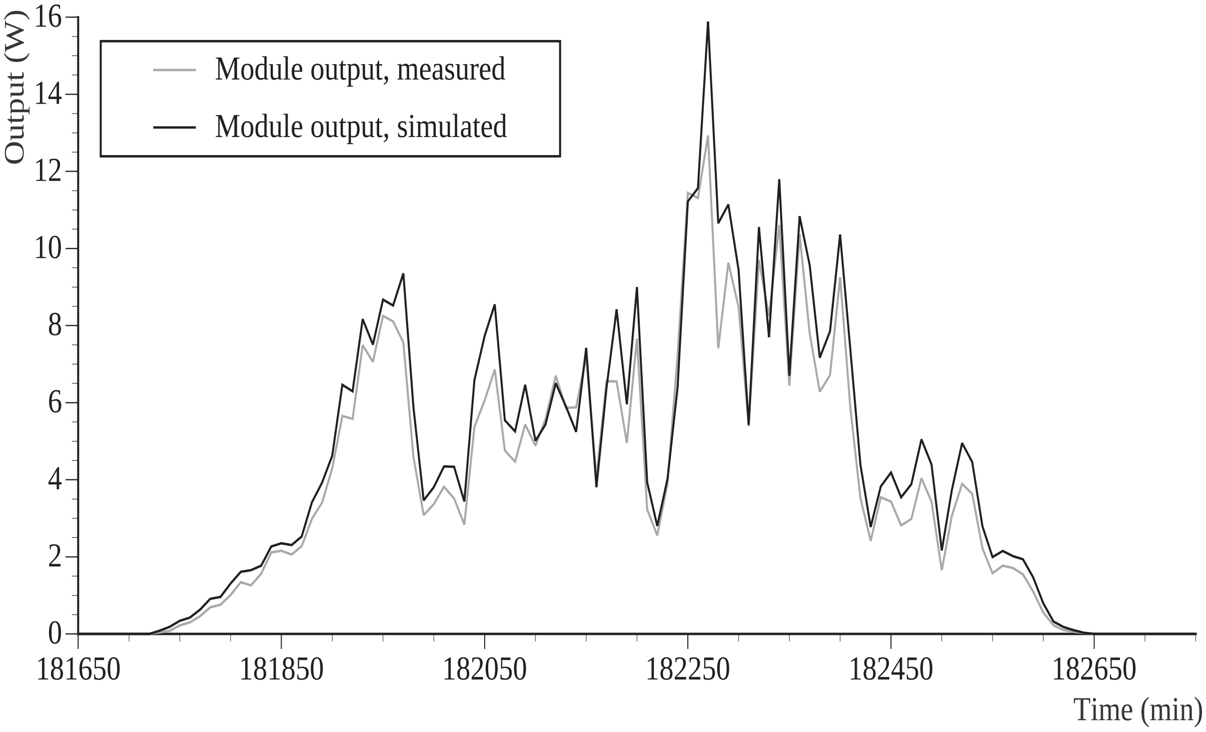


Figure 71 : Test of photovoltaic module: Comparison of simulated with measured values. Source: Spangardt (1999).

It is noticeable that for small outputs, the simulated output is somewhat higher than the measured one. The reason is probably because a constant efficiency of the power inverter is assumed in the simulation, whereas real inverters can feature losses in the part-load range. This could only be taken into account in a simulation of individual photovoltaic installations, not in the simulation of

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111.ISET (1998).

an assemblage of installations. For high irradiance and larger mounting angles, the measured radiation is higher than the simulated one. This may be attributed to the reflected radiation that is left out of account, which is of increasing importance as the mounting angle increases.

In the simulation modules for wind turbines, the correct entry of the output curves was checked first. In addition, the behavior of a simulation module on a sample day was analysed. A correct conversion of the wind speed to the hub height of the simulated wind turbines, and a correct application of the output curve to compute the output to the grid were found. Unfortunately, comparisons with real installations were not possible, since the institutes that have measured the wind turbine data are not authorized to release these data. Since, however, the output curves of the wind turbines were derived from just those data, errors in the simulation can only result from the conversion of the wind speed to the hub height of the aerogenerators. If one assumes that the logarithmic elevation equation reflects the circumstances correctly, the possible source of error is in the assumption concerning the surroundings, i.e. in the assumption of the roughness length. If one considers the roughness length 0.01 m of open terrain, and of 0.1 m of a landscape with bushes, the height conversion factor for a measurement height of 10 m for the wind speed and a hub height of 70 m has a value of 1.28 or 1.42, respectively. So if one takes the roughness length of open terrain for wind turbines in a landscape with bushes, one makes an error of 10%. It must also be taken into account that this height equation can only properly be used if the measuring station and the wind turbine are located in comparable surroundings.

The power plant options of coal, gas, solid biomass, and biogas-fired power plants have been tested with regard to the correct control of the power plant assembly, and thus the correct calculation of fuel consumption. In these tests, it was found that the modules behaved according to the specifications.

The hydroelectric and geothermal power plants were tested to see whether the power plants produce the expected output if controlled appropriately, and whether this agrees with the rated capacity. In the case of the hydroelectric plants, it was also necessary to examine whether the limitations on output due to the water level are taken into account.

Cogeneration in the household and services sectors was simulated with a test set of meteorological data, and the results were compared with manually calculated values.

In checking the storage simulation modules, the charging and discharging of the storage systems was tested. As intended, the stored energy was diminished in accordance with the efficiency of the storage systems. So the charging and discharging of the storage systems is simulated according to the specified strategy. In these modules, the source of error is presumably the assumption of constant efficiency of the storage options. If one wishes to take into account the efficiency of the storage systems as a function of the load, each storage unit must be taken into account individually for each storage option.

In the case of the simulation of the electrical load curve, it was checked whether the electrical demand is simulated correctly from the specified curves. The load-curve simulation was checked with the help of a spreadsheet program for various consumer groups on sample days.

Since the peak power plants are integrated into the import-export manager module, and respond to the demands of all regions, they were tested together with the import-export manager.

The import-export manager and the energy manager can only be tested in the context of an overall system. No errors in these modules were found during repeated simulation and evaluation of the results. As part of the tests, the energy balances were calculated by hand repeatedly, and the control response of the two modules was studied and improved.

10.8) Example of a simulation of a supply system

In the following, the energy supply curves for a few weeks are shown to illustrate the dynamics of a supply system. The examples are taken from the simulation of the Japanese power system. Energy supply of Japan in the 3rd week of the year shows the third week in January, from Monday the 14th to Sunday the 20th.

The results show the energy output of all energy suppliers in gigawatts, plotted against time. The day of the year is given on the horizontal axis, and the vertical lines separate the days from one another at midnight. Hydrogen production is not always shown completely, because it is very high at times.

The top (first) graph shows energy consumption compared with energy output. Energy output is the sum of the energy suppliers shown in the other four curves. Potential supply deficiencies can be detected there, and surplus output estimated. In the third week of January shown in the graph, we can see that a full supply is ensured at all times. Since the supply system was optimized for that goal, this full supply is available throughout the year. The second graph shows the output of the geothermal power and hydroelectric plants. The photovoltaic and wind power outputs are plotted below this. The next graph contains a results curve for the cogeneration plants in the industrial sector, and one for those in the household, commercial and services sectors. The CHP plants in the household, commercial and services sectors fluctuate according to the outdoor temperature, as described previously. The major jumps in output are due to the change-over between daytime and nighttime heating. The last graph shows the energy output or demand of the pumped-storage and peak power plants and the hydrogen production. The energy used to charge the reservoirs and for generating the hydrogen is negative in these graphs, since it is consumed. In order to obtain the course of hydrogen production, one can simply take the sum of the individual energies produced (except for the hydrogen production curve).

In the first (top) section, one can see a surplus of energy on the 15th and 16th of January. This energy comes from the high outputs from wind energy and photovoltaic systems, as one can see in the third figure. Hydrogen is generated from the energy surplus. In the second curve, one can see that hydroelectric and geothermal power plants are producing less energy at that time, since less energy is required from controllable suppliers. They are not shut down completely, since a few regions need this energy.

On January 18th, energy production and demand coincide exactly. This is made possible by precise adjustment of the controllable energy suppliers. The wind energy and photovoltaic output is considerably less on that day than on the other days, and for that reason the controllable energy suppliers run almost at full capacity. The last graph, which covers the charging and discharging of the reservoirs and the peak power plants, is very interesting in this context. As described previously, 1 gigawatt capacity of the peak power plants is started up before the reservoirs are discharged. If that is not enough, the pumped-storage turbines are used to cover the remaining demand. This happens on Friday evening, for example. They are then refilled when there is a surplus of energy, for example Friday night.

On Sunday, January 20th, one can see what happens if much too much energy is available. On Sundays, the demand for energy is considerably less than on weekdays, since most offices are closed and many energy consumers are not working. Since this does not affect the fluctuating energy suppliers, there is a surplus of energy on most Sundays. The reservoirs can be refilled over the weekend. In addition, all the controllable energy suppliers can be throttled back. Even the output of the cogeneration plants is lowered. In the last curve, one can see that hydrogen production is especially high on that day.

The results in Figure 73 show the supply of the Hokkaido West region from the ERJ model. Let us consider these results in order to examine a region whose energy supply exceeds demand for almost all the year. As one can see, a very large proportion of the energy is generated by wind turbines and geothermal power plants. This is possible because the region has a very low population density and pronounced geothermal anomalies. The photovoltaic output is so low because there are hardly any roof surfaces on which photovoltaic arrays could be installed.

As one can see, many controllable energy suppliers produce energy although no more energy is needed at all in the region. This shows clearly that the import-export manager takes over control partially, and starts up the power plants because power is still needed in other regions.

The results for a region of the ERJ model that, due to its high population density, is not able to supply itself completely for most of the year are shown in Figure 74. These graphs show the same week in Kanto. Here, conditions are exactly the opposite. There is very little room for wind turbines, since the region is very densely populated. However, much energy can be obtained from cogeneration plants, since the population also needs a lot of heat, and electricity can be cogenerated during the production of heat. In the results shown, the energy demand can only be met on Sundays, since energy consumption is considerably lower on that day than on any other day of the week.

As one can see, on days with low photovoltaic output, the energy manager in the region switches on the pumped-storage power plants, in order to generate electricity from their stored energy. The energy manager is only able to throttle back the hydroelectric plants on Sunday, since enough energy is available on that day. Since this region is hardly able to supply itself, energy production here is only influenced by the import-export manager inasmuch as it imports energy into the region when needed, in order to ensure supply.

Figure 75 shows the Chugoku region in the same week. These graphs are discussed here because they show once again the influence of the import-export manager on the charging and discharging of the storage systems. Chugoku is largely able to cover its energy demand itself, without generating a surplus in the process. The region is able to have large areas of photovoltaic arrays, and already has numerous hydroelectric plants. Furthermore, demand is only about one fifth of Kanto’s energy demand.

As one can see, the reservoirs are filled on Thursday and Friday night, although the region does not produce surplus energy. The reason is that there is a surplus of output in Japan as a whole. The import-export manager stores this in the reservoirs in Chugoku, since there is still free capacity here. In the daytime, the reservoirs are discharged partially, although there is no lack of supply in Chugoku. This is done in order to supply the rest of Japan with power. Here too, the import-export manager controls the energy output of the pumped-storage power plants.

The double peak in the photovoltaic output is due to the fact that in Chugoku most of the solar-cell surfaces are computed from meteorological data from two different longitudes. Therefore, the maximum irradiance of a day occurs first at the eastern, and a little later at the western weather stations. The result is this double peak in the curve.

Figure 76 shows a summertime result of the ERJ simulation. Due to the high temperatures, the cogeneration plants are not used for space heating in this month, but only to heat water. Therefore, the course of the curve for the cogeneration plants in the household and services sector (“Cogen(Com,Res)”) in the results is no longer weather-dependent, nor does one see the night-time lowering of temperature. Energy supply just meets demand during the summer months, and cannot be used for hydrogen production. But this is due less to the low CHP output than to the poorer wind conditions than in the rest of the year.

The results in Figure 77 and Figure 78 are good examples of what the energy supply of a model region might look like if coal-fired and gas-fired power plants are included in the energy system. The control mechanisms are the same as in the ERJ simulation. In the graphs shown here, the gas-fired power plants are always regulated before the coal-fired ones, so that their output varies considerably more within the weeks shown than that of the coal-fired power plants. In Figure 77 there is a very large surplus throughout the week, while in Figure 78 the output of the fossil-fuel power plants has to be increased towards the end of the week because of the low wind-energy output. The week shown in Figure 78 is a week in summer, as well. Therefore, the cogeneration plants in the household and services sector are not run for heating purposes during this week.

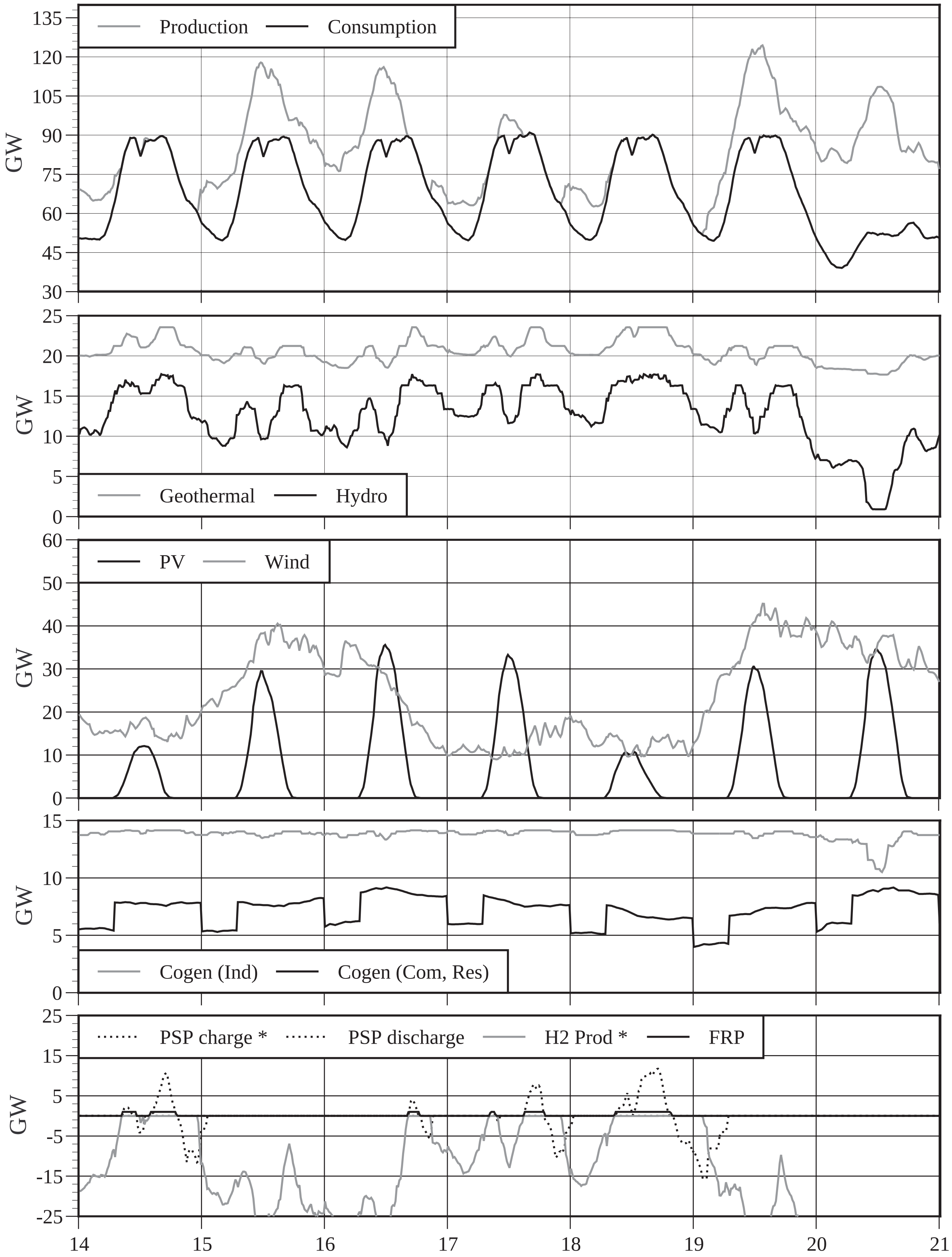


Figure 72 : Energy supply of Japan in the 3rd week of the year. Source: ERJ.

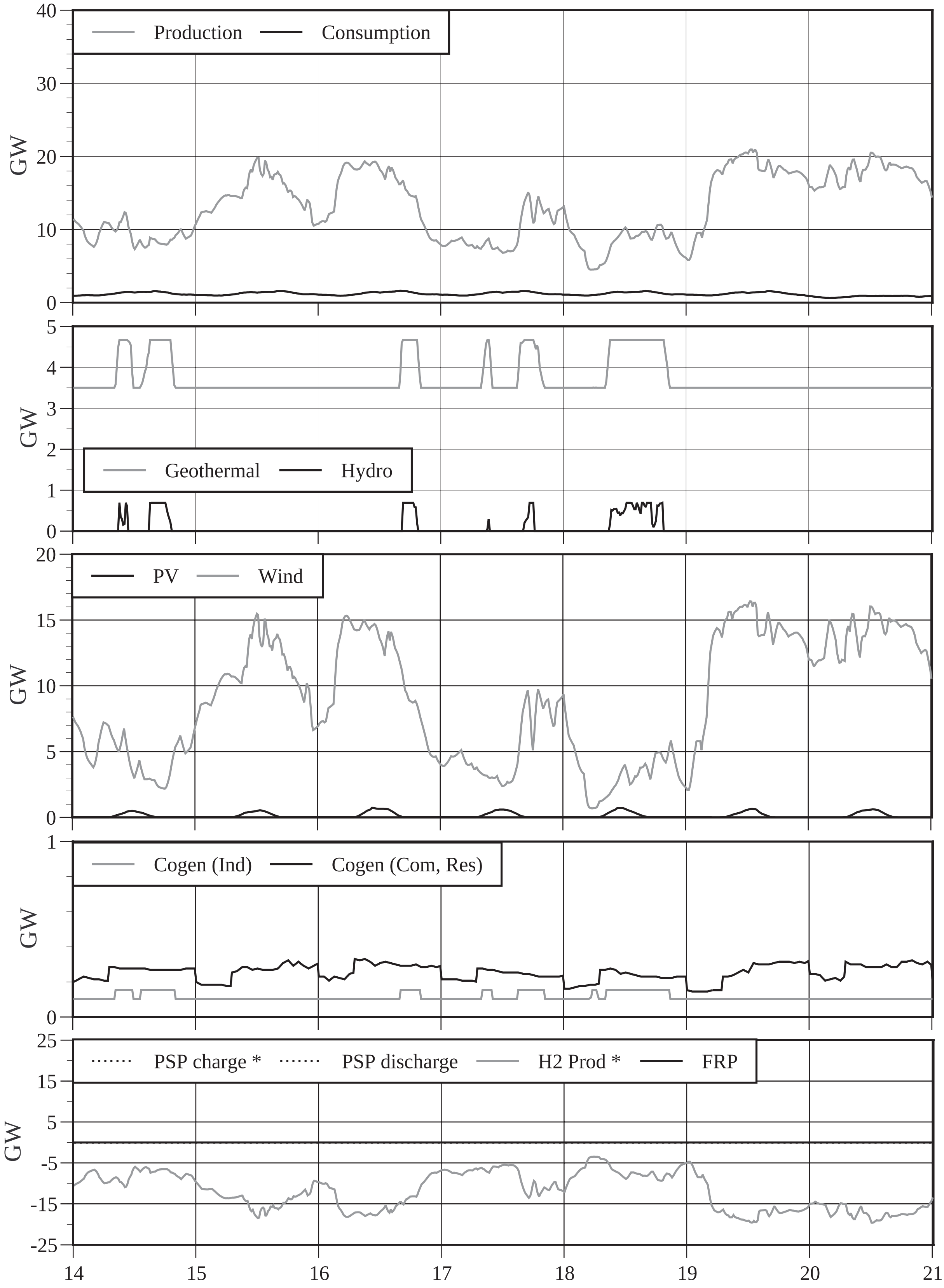


Figure 73 : Energy supply of the Hokkaido West region of the Japanese energy model in the 3rd week of the year. Source: ERJ.

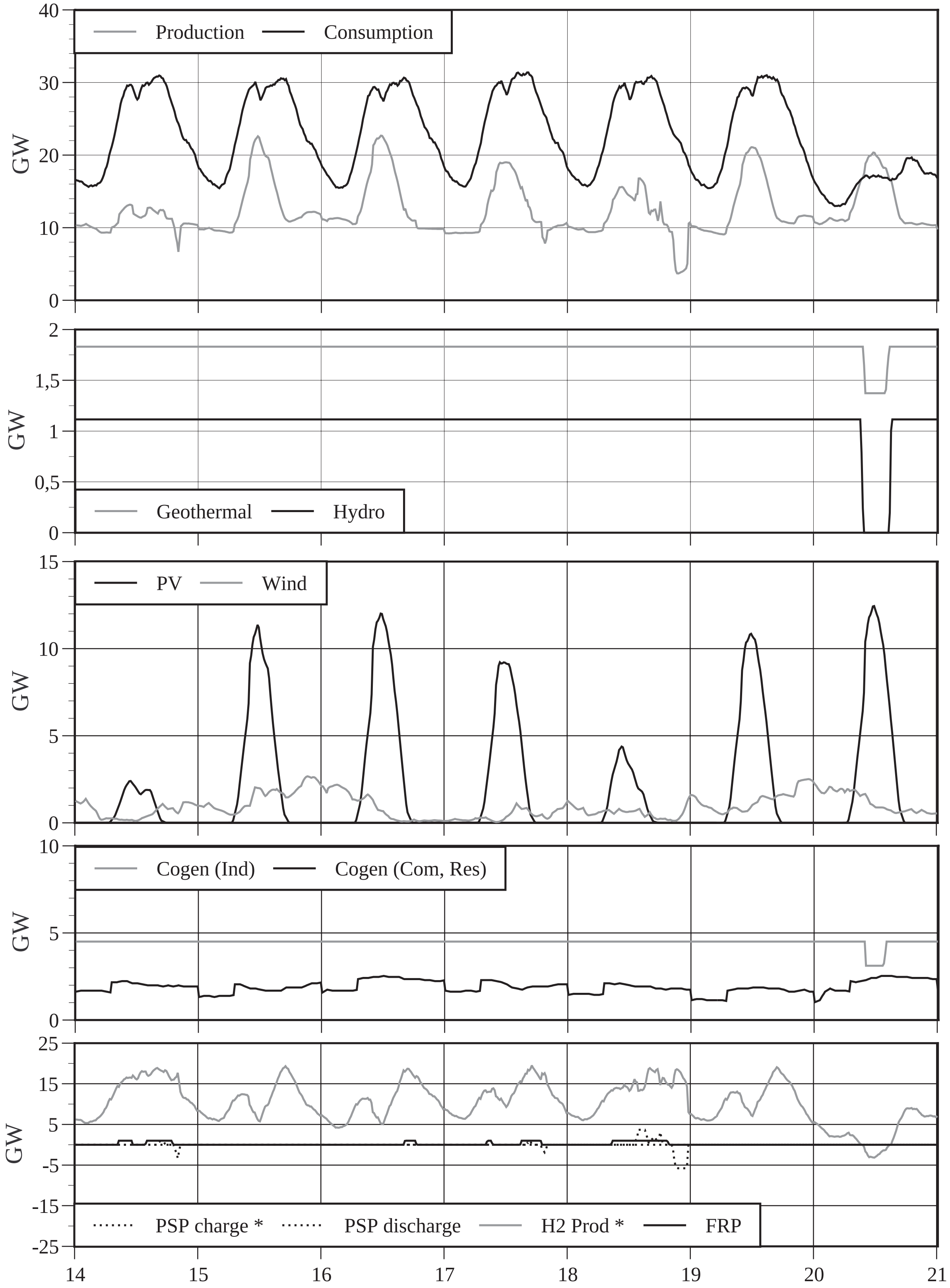


Figure 74 : Energy supply of the Kanto region of the Japanese energy model in the 3rd week of the year. Source: ERJ.

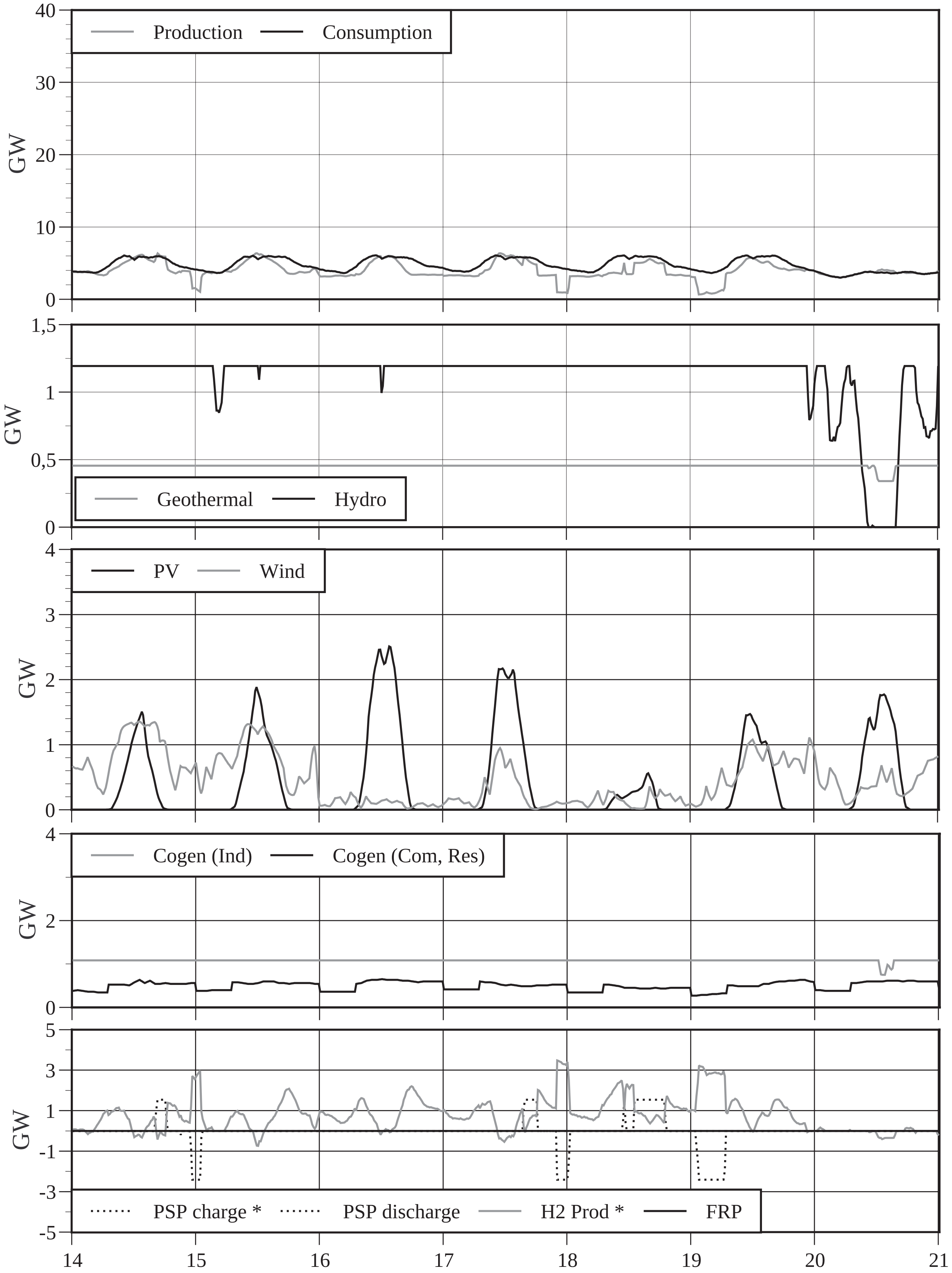


Figure 75 : Energy supply of the Chugoku region of the Japanese energy model in the 3rd week of the year. Source: ERJ.

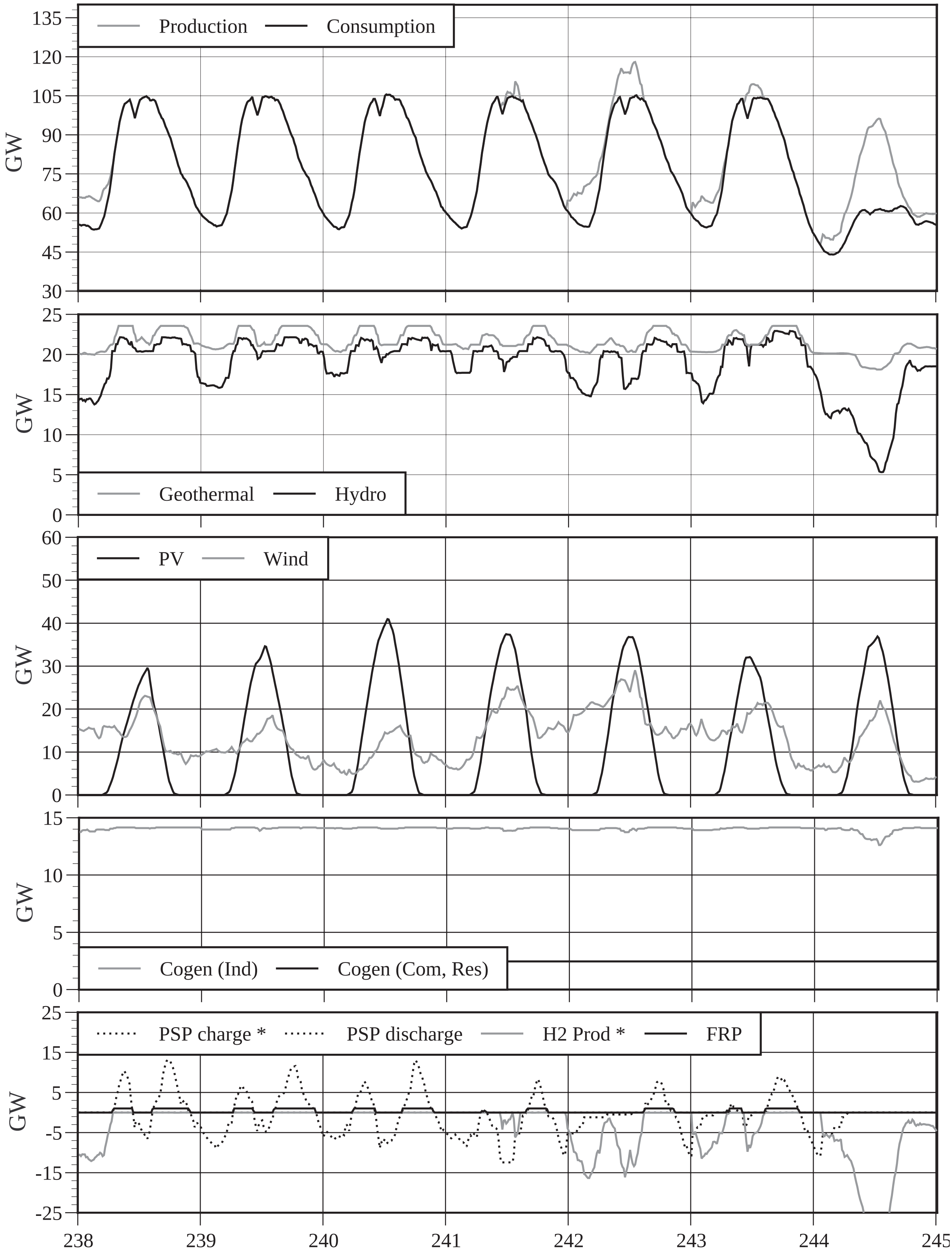


Figure 76 : Energy supply of Japan in the 35th week of the year. Source: ERJ.

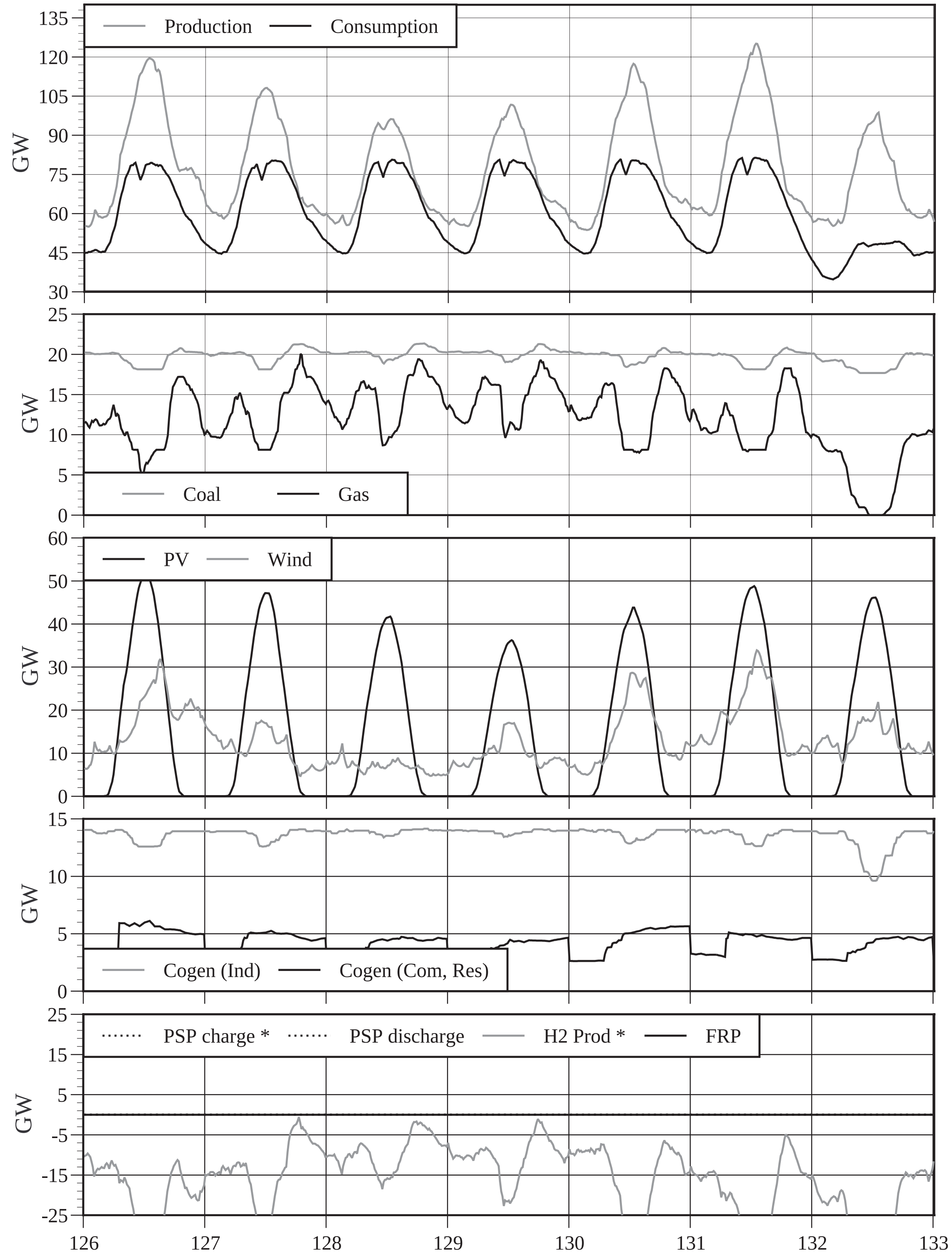


Figure 77 : Energy supply of a model region, including coal-fired and gas-fired power plants. Source: ERJ.

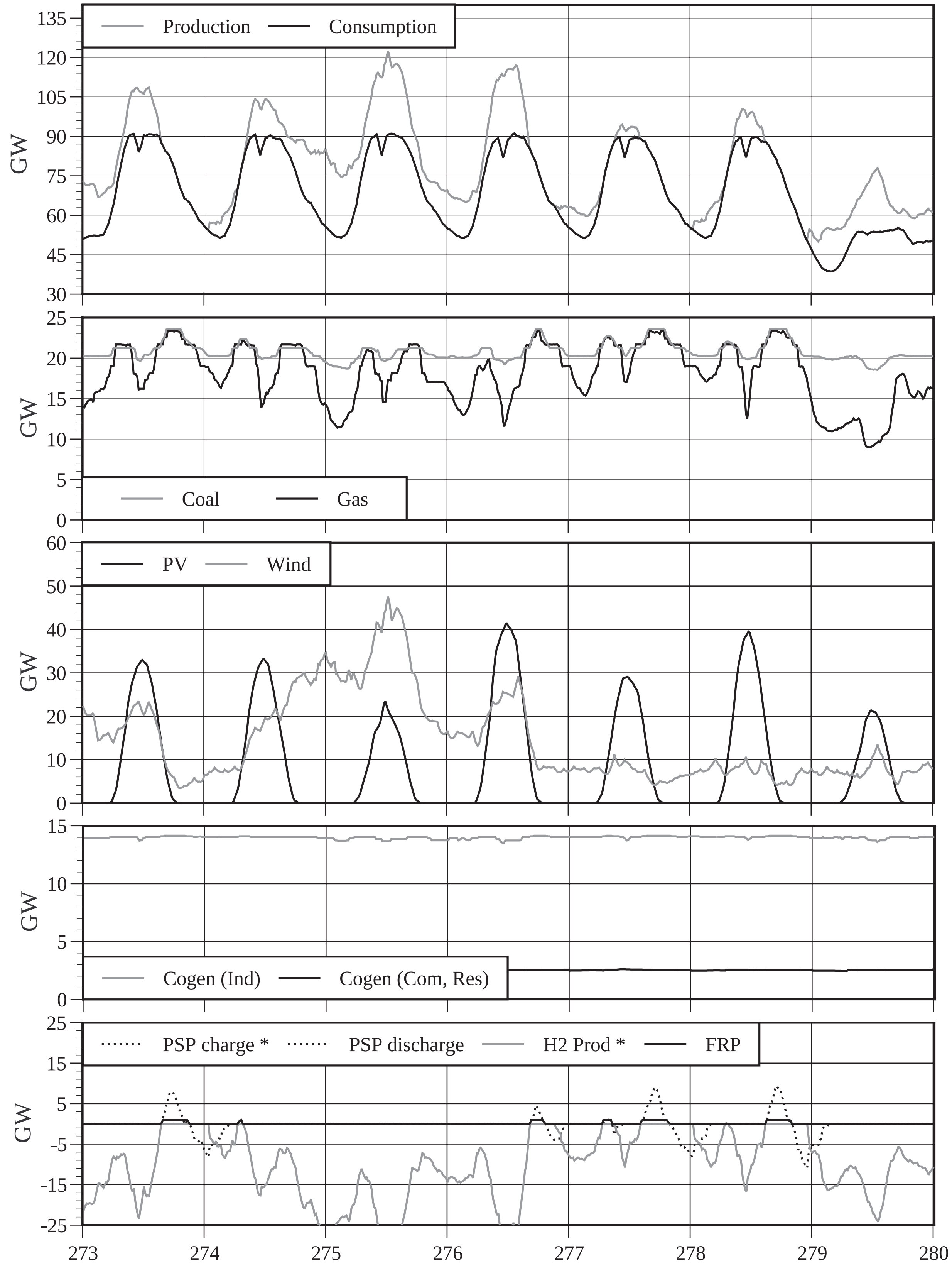


Figure 78 : Energy supply of a model region, including coal and gas power. Source: ERJ.

11 Appendix - Scenario Tables

	Scenario 1		**Scenario 1 (population change)**		**Scenario 2 (offshore attack)**		**Scenario 2 (offsh + population)**		**Scenario 3 elec shift**		**Scenario 3 elec & pop 100%**	
Electricity												
Photovoltaic (PJ)	296		296		532		532		665		532	
Area (sqm/cap)		3,2		3,2		4,8		4,8		6,0		4,8
Efficiency		15%		15%		18%		18%		18%		18%
Peak power (MW)		60686		60686		109234		109234		158931		109234
Additional PV on facades (PJ)									333			
Additional facade-area (sqm/cap)										6,0		
Peak power (MW)										158931		
Solarthermal Plants (PJ)	0		0		0		0		616		380	
Area (sqkm)		0%		0%						600		370
Efficiency		0,2		0,2						20%		20%
Peak power (MW)												
Wind (PJ)	592		592		1624		1624		2902		2456	
Installation onsh/offsh (factor of Scen 1)	1x	1x		1x	1	4	1	4	2,5x	4,5x	2	4,0
Efficiency		25%		25%						30%		30%
Number of onshore plants (units)		21933		21933		21933		21933		54833		32900
Installed power onshore (MW)		43725		43712		43725		43725		109312		65587
Average power onshore plants (MW)		2,0		2,0		2,0		2,0		2,0		2,0
Number of offshore plants (units)		5096		5096		20384		20384		22932		20384
Installed power offshore (MW)		13192		13205		89632		89632		114660		101920
Average power offshore plants (MW)		2,6		2,6		4,4		4,4		5,0		5,0
Geothermal Power Plants (PJ)	651	eta 40%	651	eta 40%	1124	eta 40%	1124	eta 40%	1336		1169	eta 40%
Used geothermal potential		25%		25%		35%		35%		40,0%		35%
Installed power (MWel)		22901		22901		26718		26718		30535		26718
Full load hours		7000		7000		8100		8100		8100		8100
combine with ORC	eta 18%	yes	eta 18%	yes	eta 18%	yes	eta 18%		eta 20%	yes	eta 18%	yes
Water Power Plants (PJ)	452		452		452		452		452		452	
Biomass (PJ)	0			?	0		0		0		0	

	Scenario 1		**Scenario 1 (population change)**		**Scenario 2 (offshore attack)**		**Scenario 2 (offsh + population)**		**Scenario 3 elec shift**		**Scenario 3 elec & pop 100%**	
Fast reacting power plants (PJ)	5		5		5		5		5		5	
Cogeneration in households (PJ)	139		139		139		139		139		139	
Cogeneration in industry (PJ)	437		437		437		437		437		437	
total electricity	2572		2572		4313		4313		6885		5570	
storage loss	7		7		7		7		7		7	
electricity surplus	464	0,8	892	0,8	2202	0,8	2633	0,8	4777	0,85	3896	0,85
hydrogen production	371		714		1761		2107		3096		2854	
								remaining surplus:	1134		538	
Heat												
Additional solarthermal heat production in industry (PJ)	0		0		342		342		683		342	
installation increased by (factor)				0,0		1,0		1,0		2,0		1,0
additional area (sqkm)				0		257		257		514		257
Cogeneration in households (PJ)	232		232		232		232		232		232	
Cogeneration in industry (PJ)	728		728		728		728		728		728	
Solarthermal collectors (PJ)	1789		1789		1789		1789		1789		1789	
total heat	2749		2749		3091		3091		3432		3091	
storage loss	292		232		292		232		292		232	
heat surplus	-1746		-823		-1405		-481		-42		4	
								remaining electrical surplus gives heat (at eta 90%):	1021		485	
Fuels												
fuel production (electricity)	371		714		1761		2107		3096		2854	
fuel consumption (cogeneration)	1920		1920		1920		1920		1920		1920	
fuel consumption (heating plants)	1984		935		1597		547		48		-4	
total fuels demand	4709		3075		2932		1294		48		-4	
Energy Supply												
total supply [PJ]	5.321		5.321		7.403		7.403		10.317		8.661	
thereof domestic fuel production	371		714		1.761		2.107		3.096		2.854	
resulting hydrogen import	4.709		3.075		2.932		1.294		48		-4	
percentage covered	53%		63%		72%		85%		100%		100%	
percentage covered (system gross supply / energy demand)	71%		89%		99%		124%		138%		146%	

	Scenario 1		**Scenario 1 (population change)**		**Scenario 2 (offshore attack)**		**Scenario 2 (offsh + population)**		**Scenario 3 elec shift**		**Scenario 3 elec & pop 100%**	
Fuel imports	**Scenario 1**		**Scenario 1 (population change)**		**Scenario 2' (offshore attack)**		**Scenario 2' (offsh + population)**		**Scenario 3'' elec shift**		**Scenario 3'' elec & pop**	
regional produced hydrogen (PJ)	371		714		1761		2107		3096		2854	
hydrogen import (PJ)	4709		3075		2932		1294		48		-4	
Import share (Related to the supply of 1999)	20,5%		13,4%		12,8%		5,6%		0,2%		0,0%	

Source: ERJ.

Table 26 : Supply overview of the different „Energy Rich Japan“ - ERJ Scenarios

12 Appendix - Weekly Figures of the Results of the Simulation

The following figures show the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower.

Legend :

Production = Total production of electricity in Japan,
Consumption = Total electricity demand in Japan,
Geothermal = Electricity produced by geothermal plants,
Hydro = Electricity produced by Hydropower plants,
PV = Electricity produced by photovoltaic Installations,
Wind = Electricity produced by windmills,
Cogen (Ind) and Cogen (Com, Res) = Electricity produced by cogeneration technologies in industrial, commercial and residential sector,
PSP (charge, discharge) = Electricity stored or retrieved in Pumped Hydro Storage Plants,
H2 Prod = Electricity used by hydrogen Production,
FRP = Electricity produced by Fast Reacting Power Plants using Hydrogen.

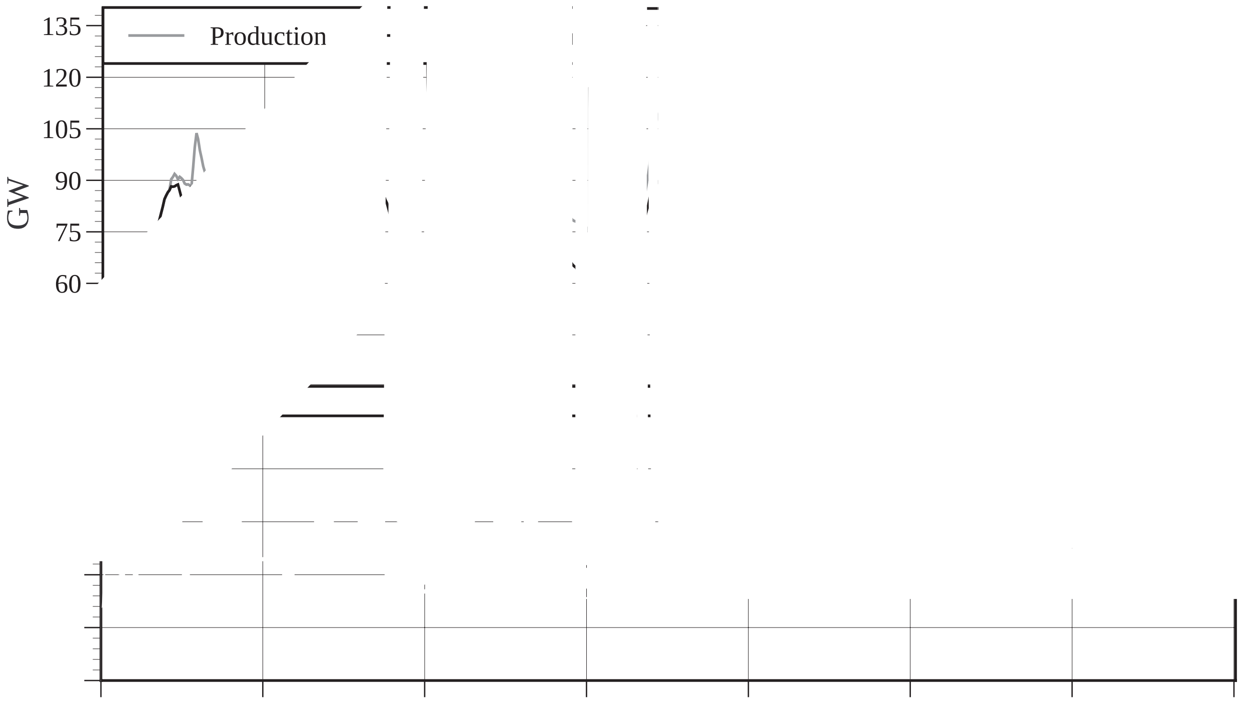


Figure 79 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 1. Source: ERJ.

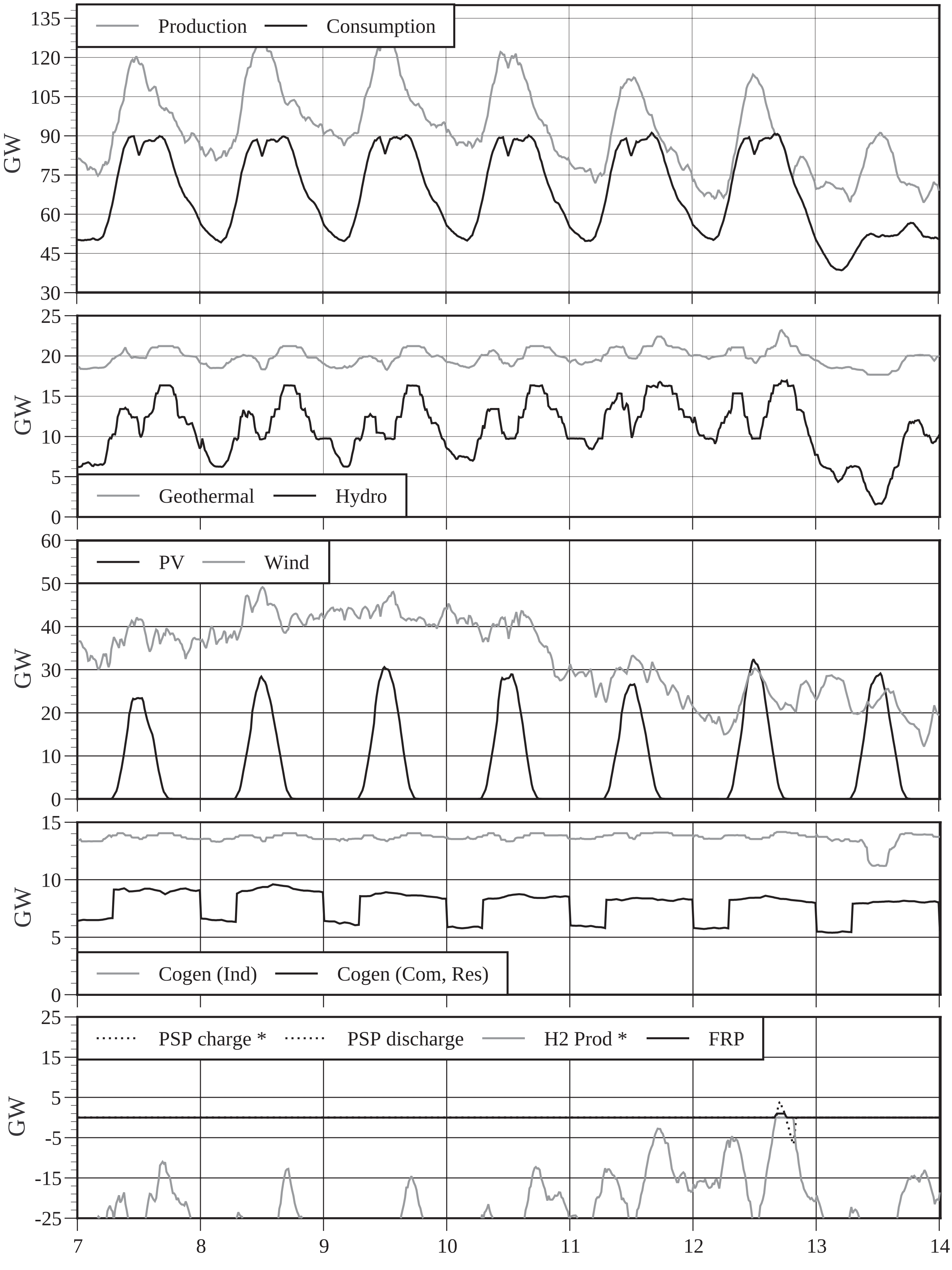


Figure 80 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 2. Source: ERJ.

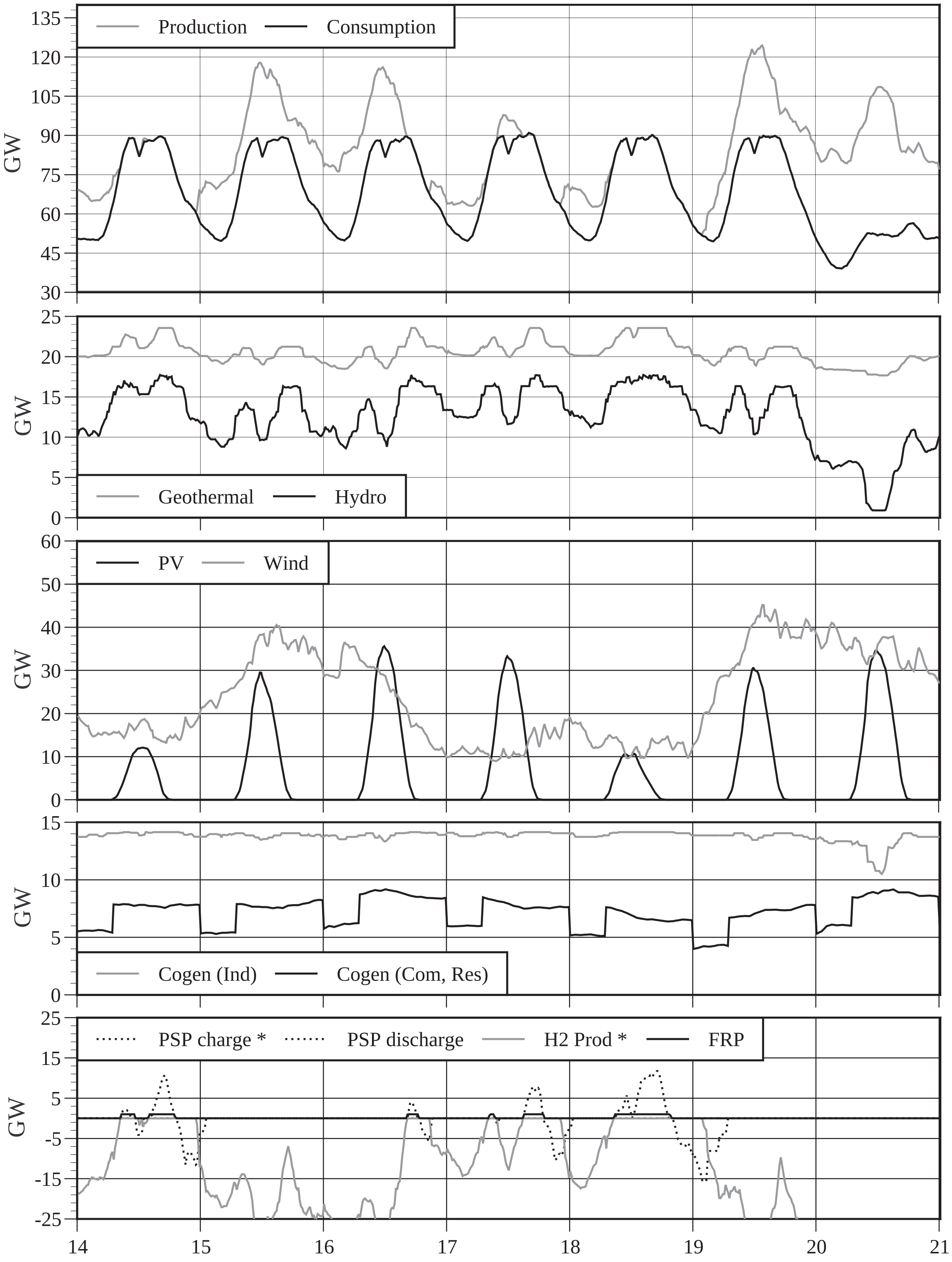


Figure 81 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 3. Source: ERJ.

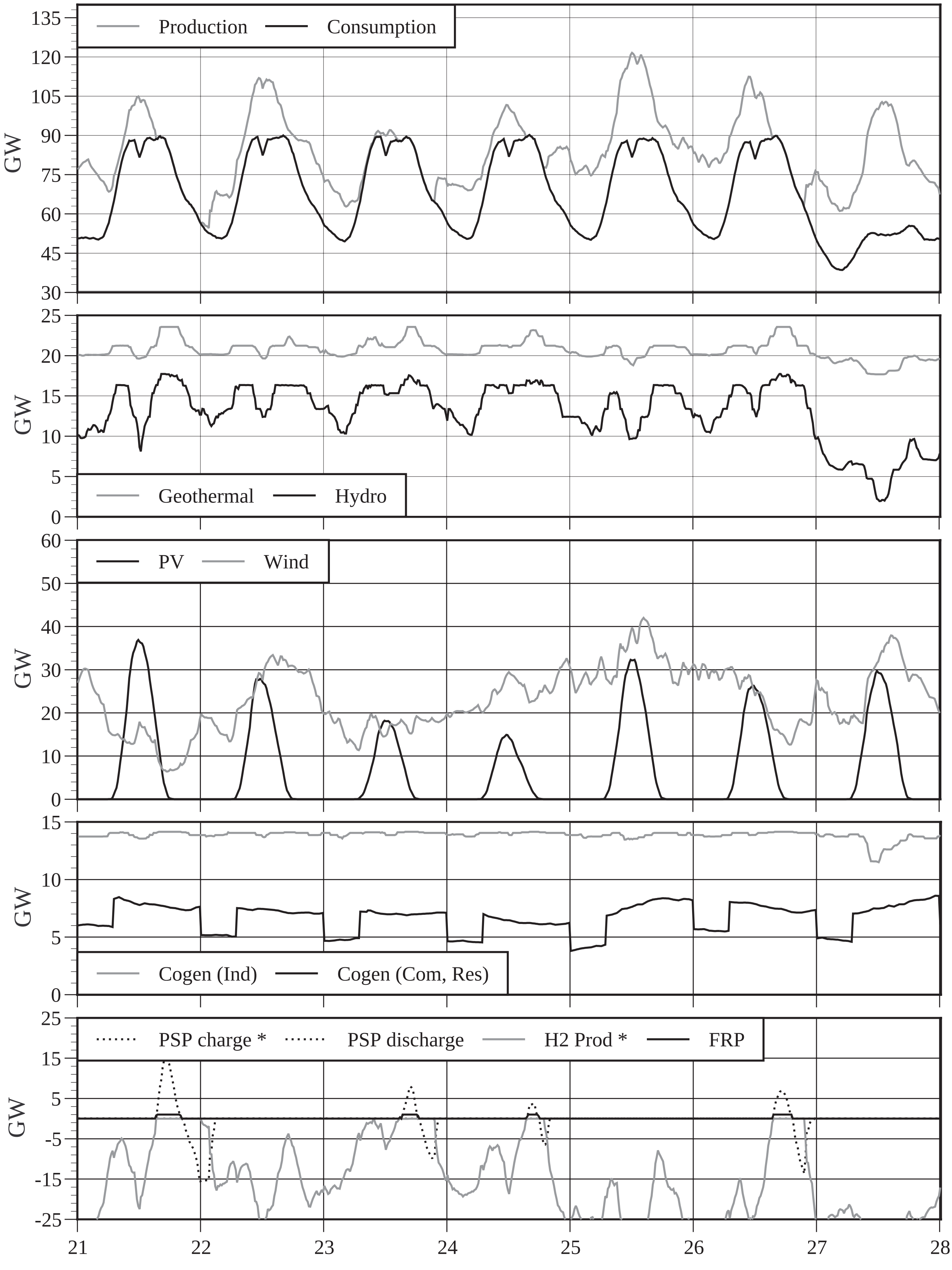


Figure 82 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 4. Source: ERJ.

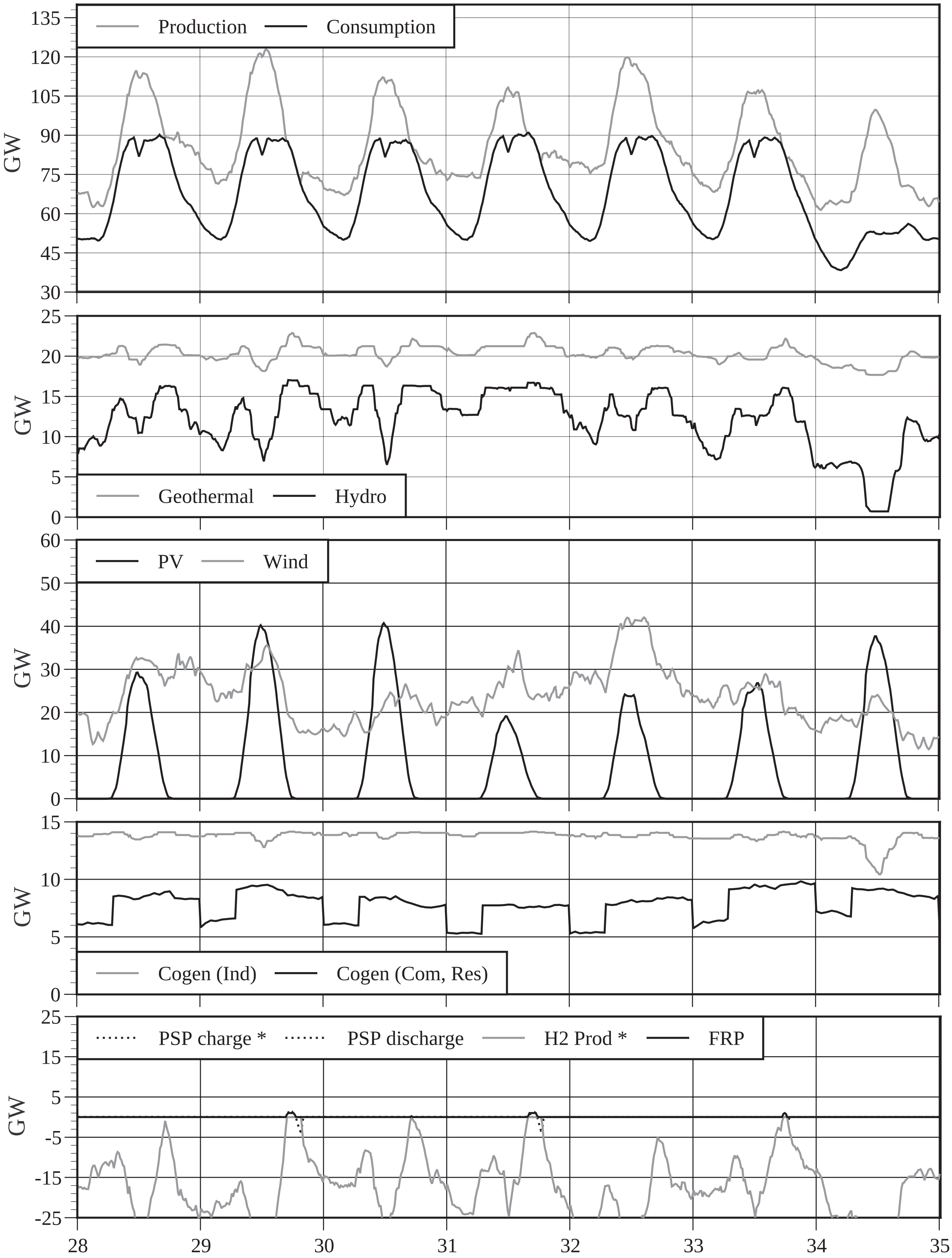


Figure 83 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 5. Source: ERJ.

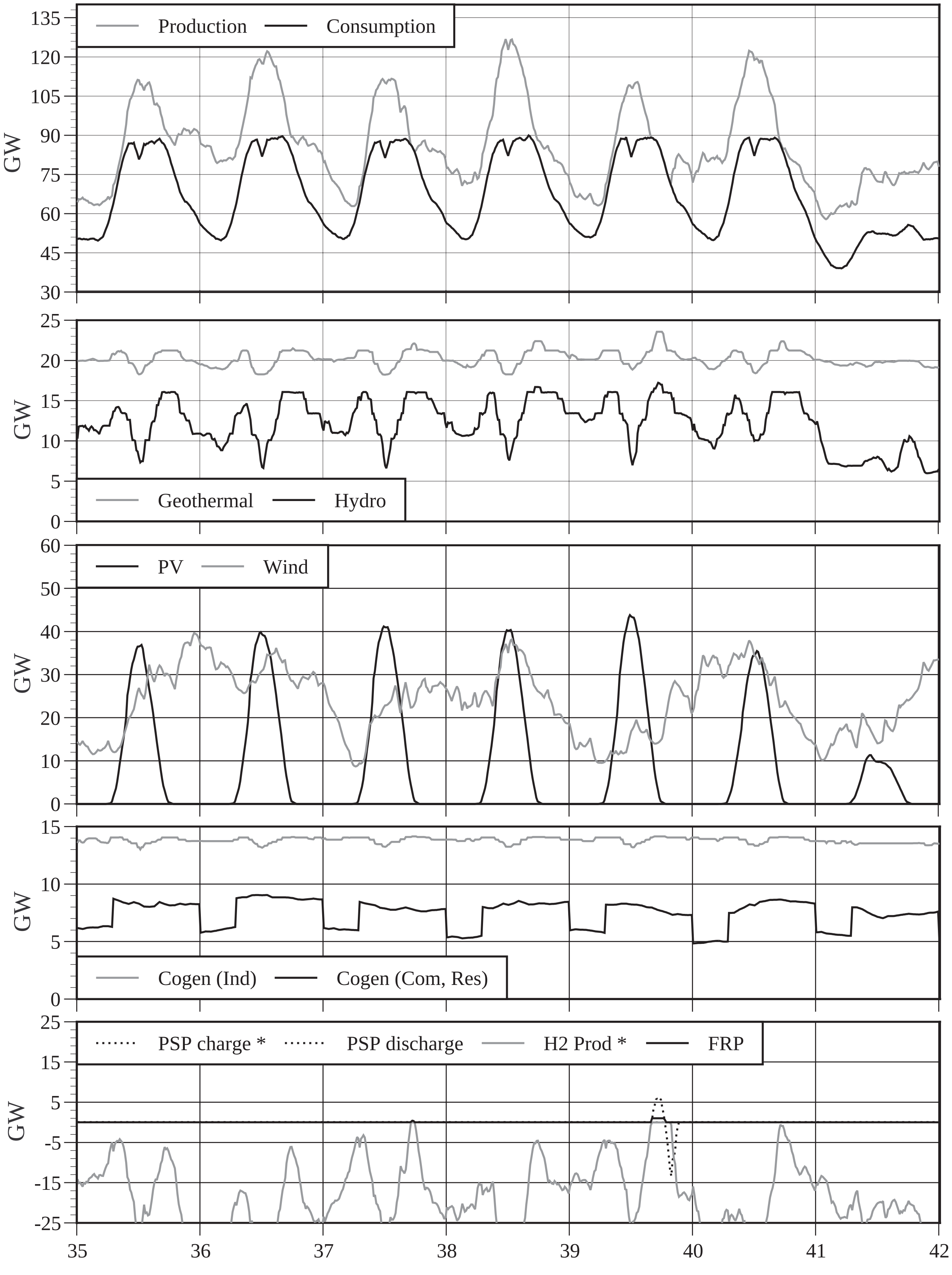


Figure 84 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 6. Source: ERJ.

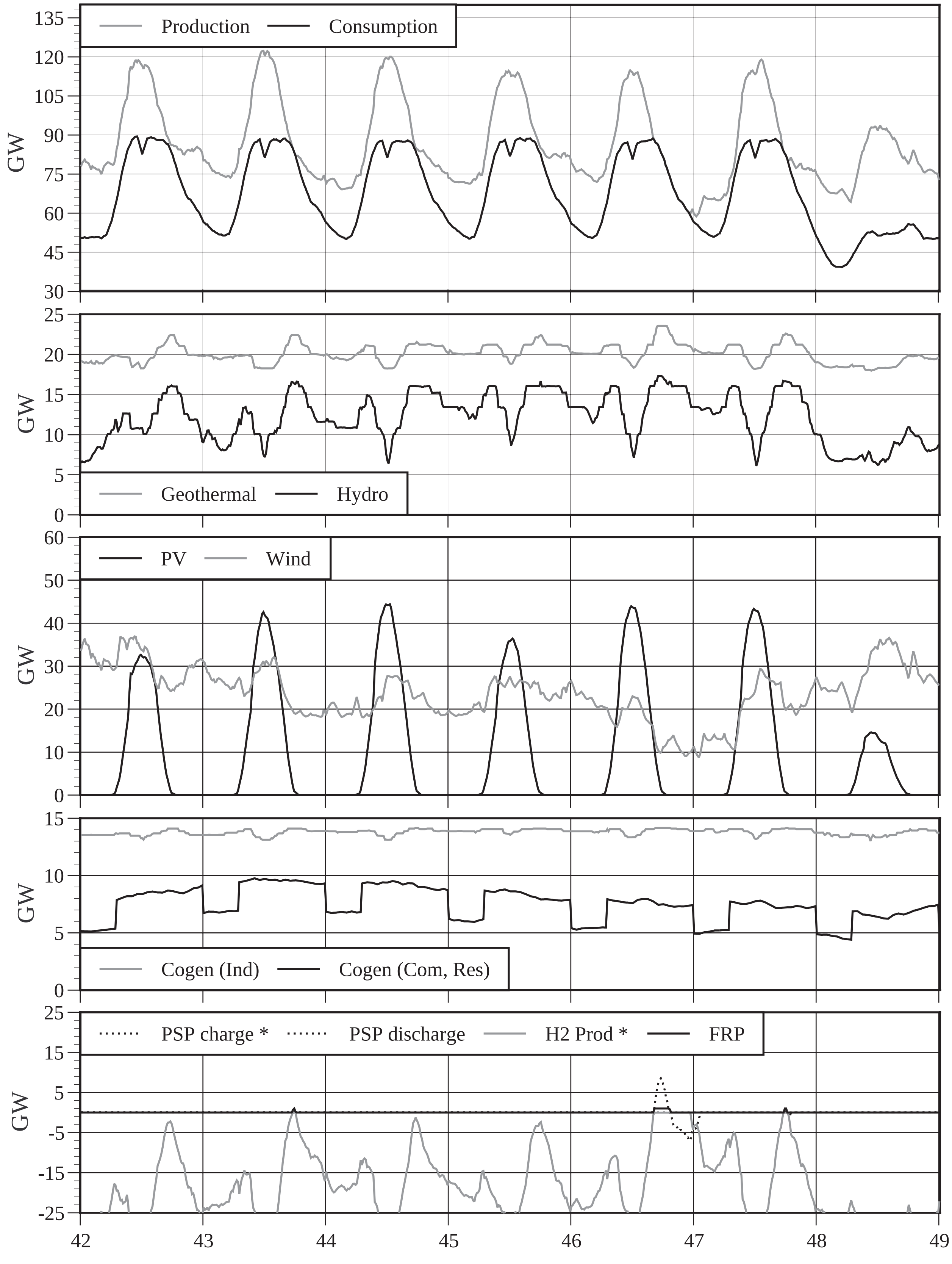


Figure 85 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 7. Source: ERJ.

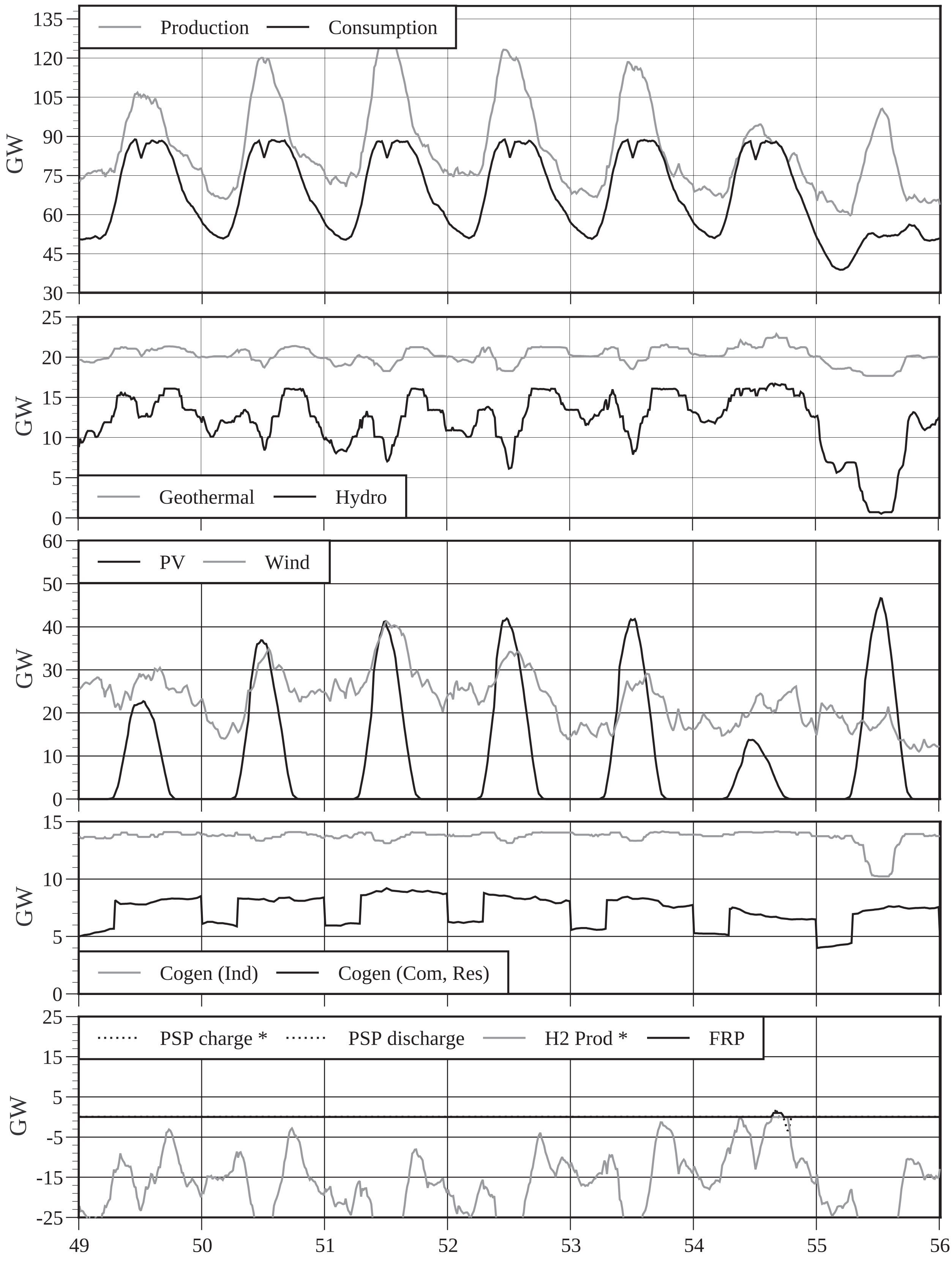


Figure 86 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 8. Source: ERJ.

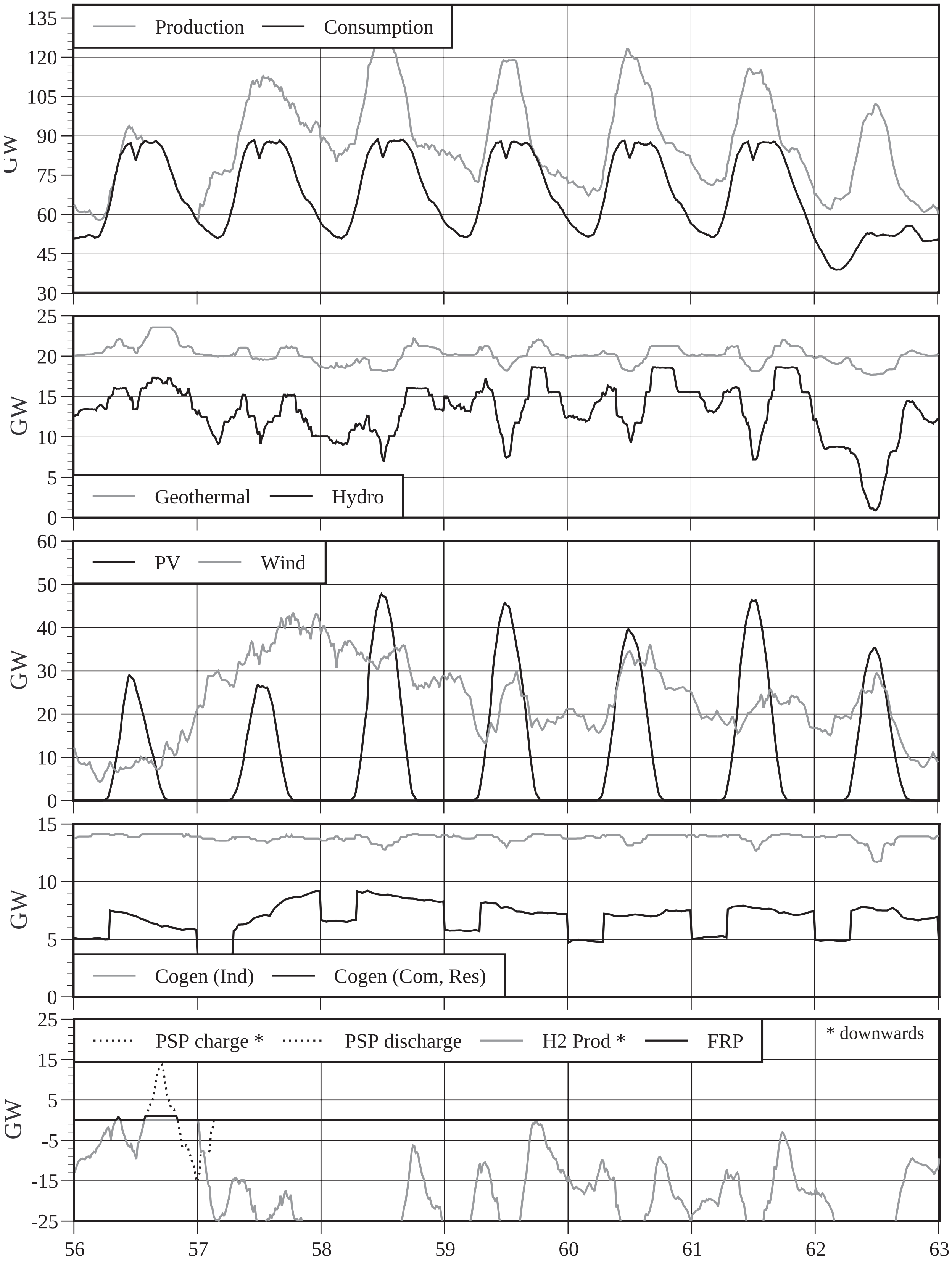


Figure 87 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 9. Source: ERJ.

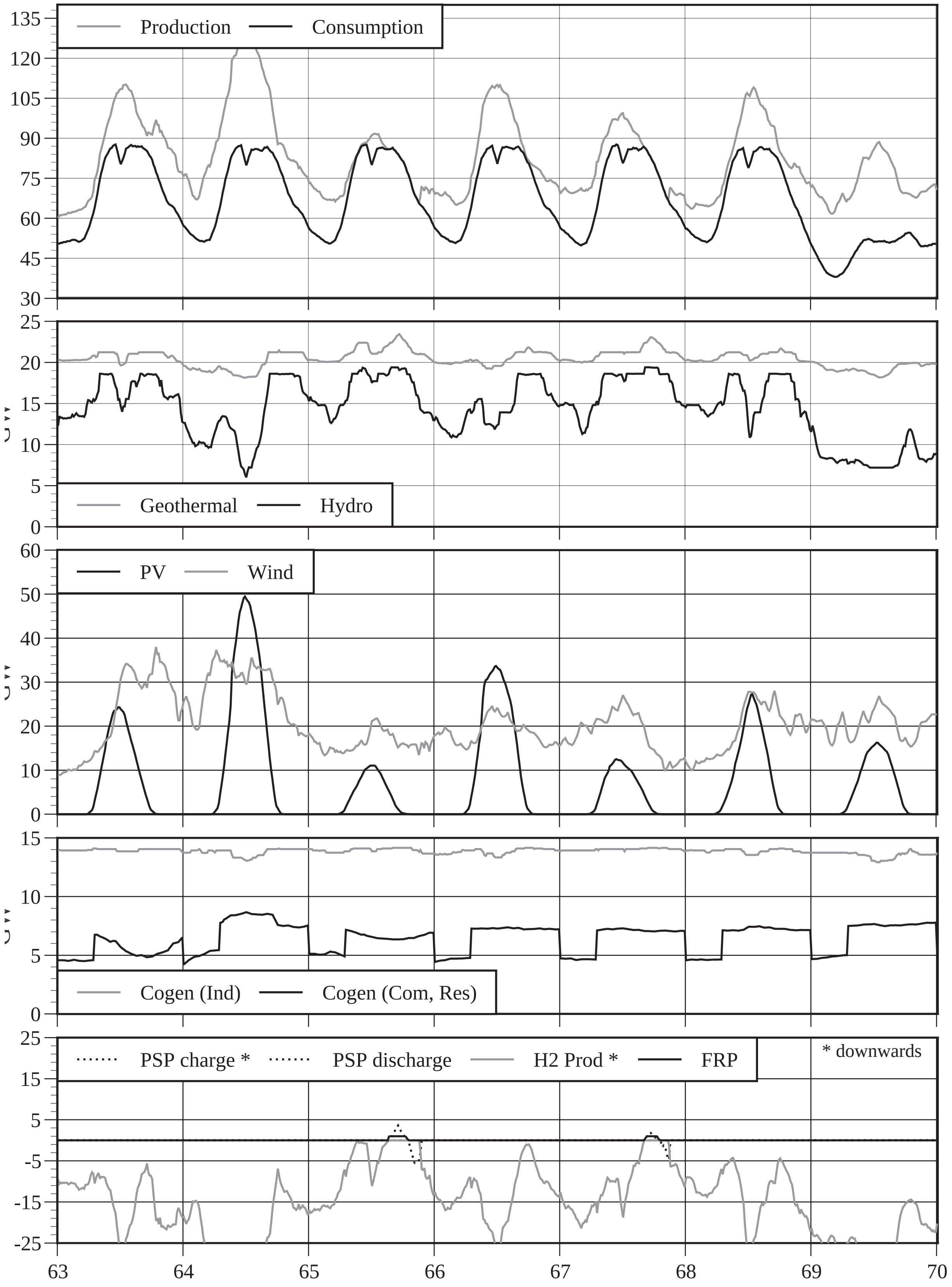


Figure 88 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 10. Source: ERJ.

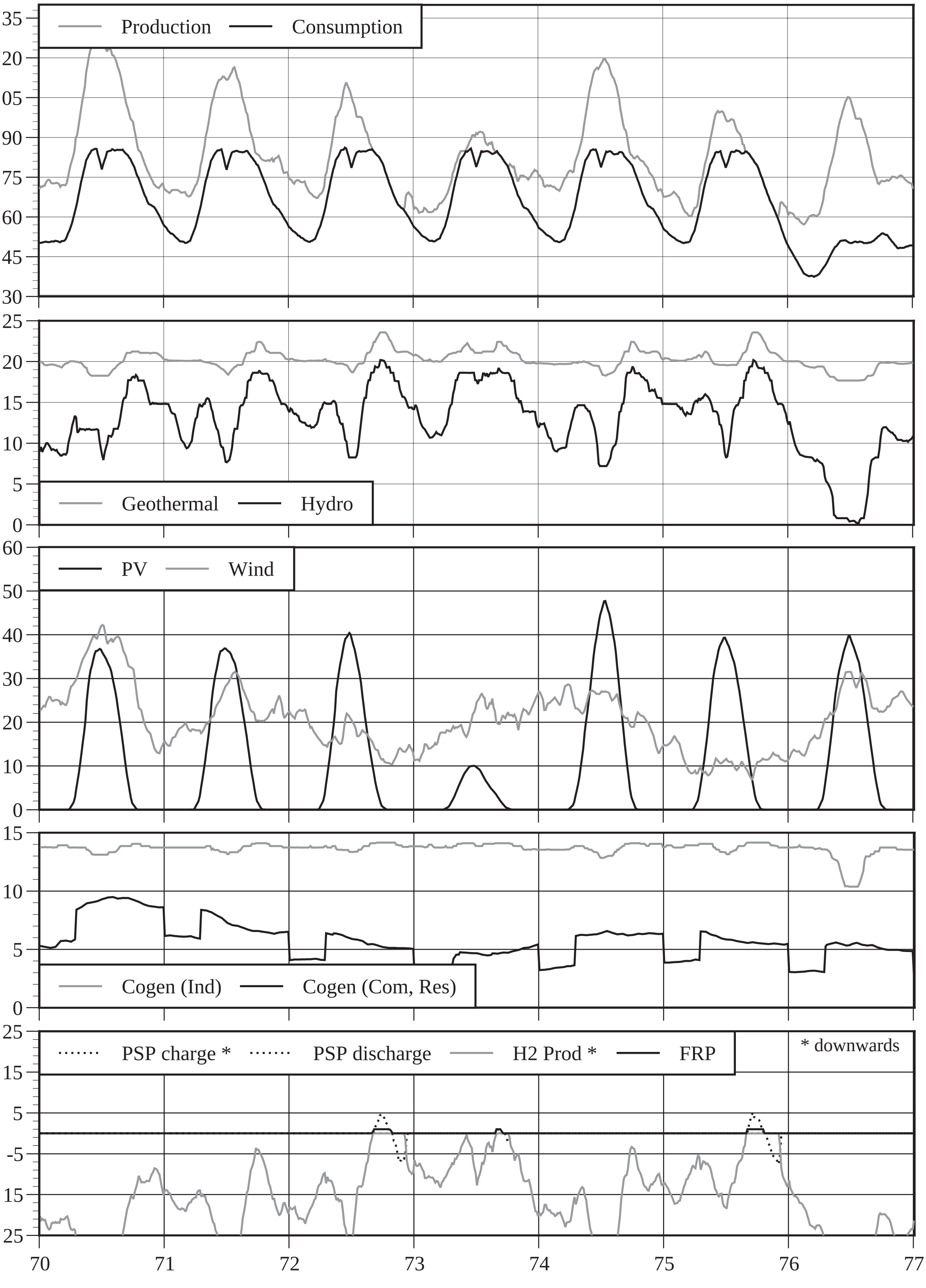


Figure 89 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 11. Source: ERJ.

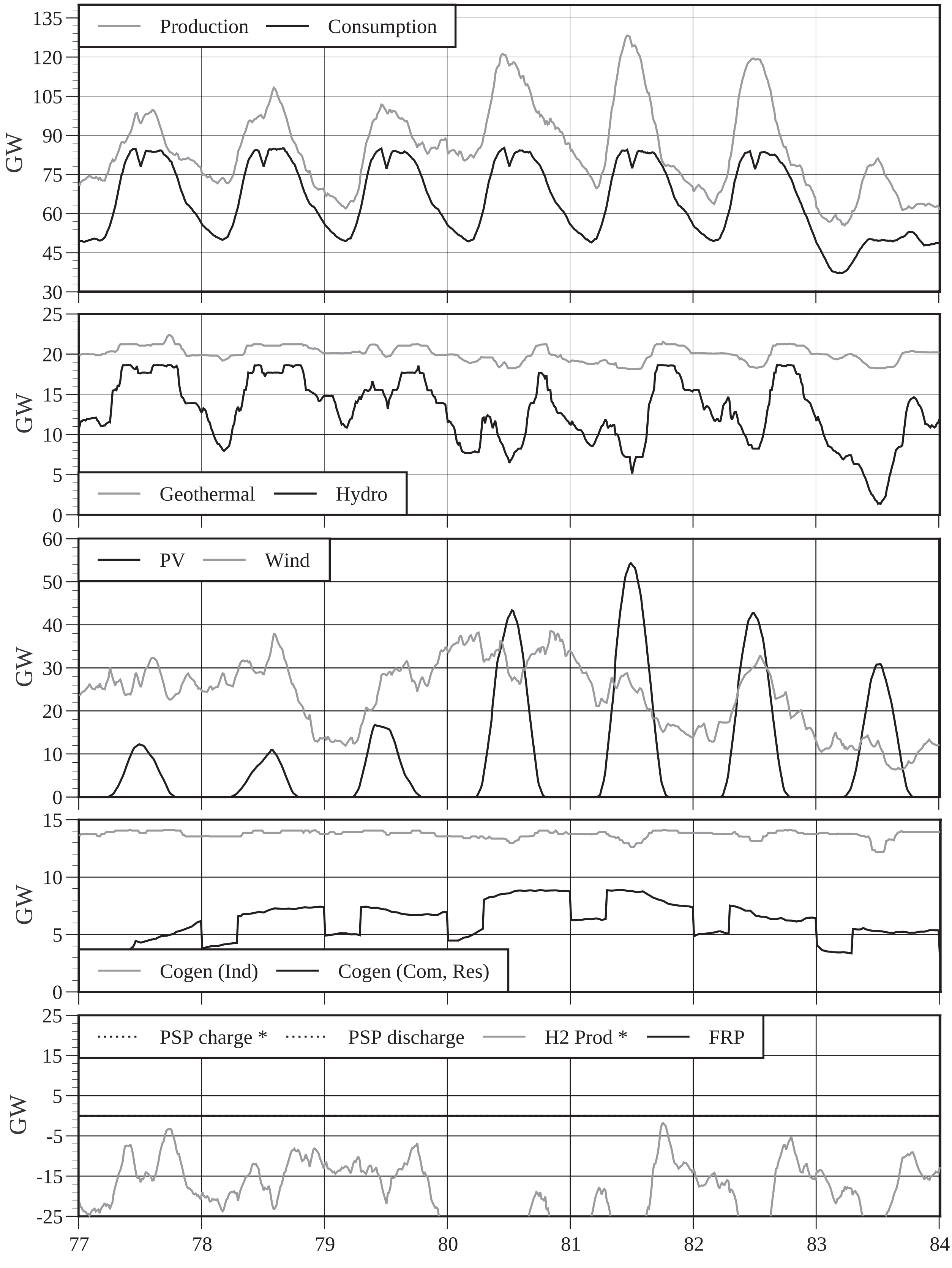


Figure 90 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 12. Source: ERJ.

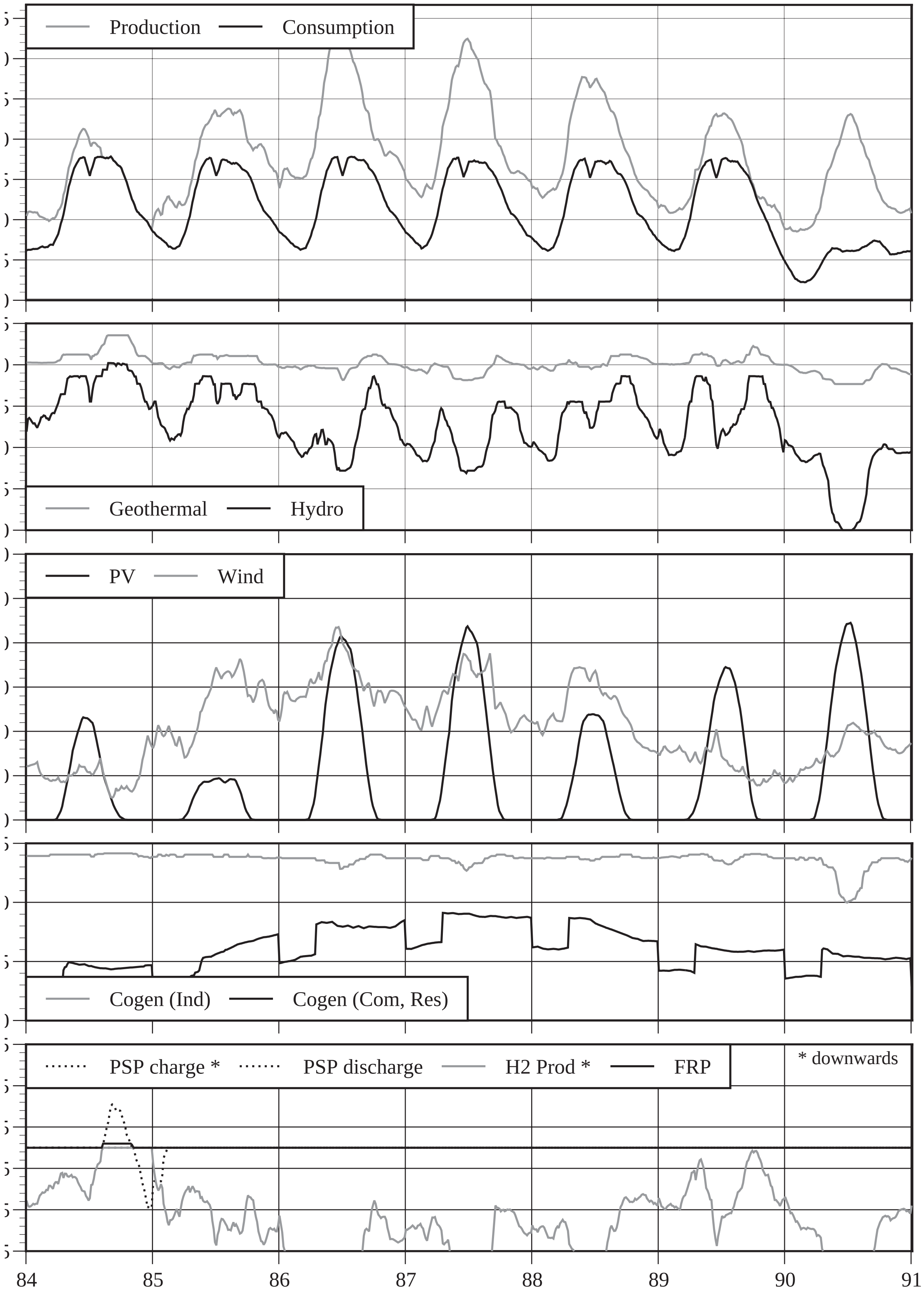


Figure 91 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 13. Source: ERJ.

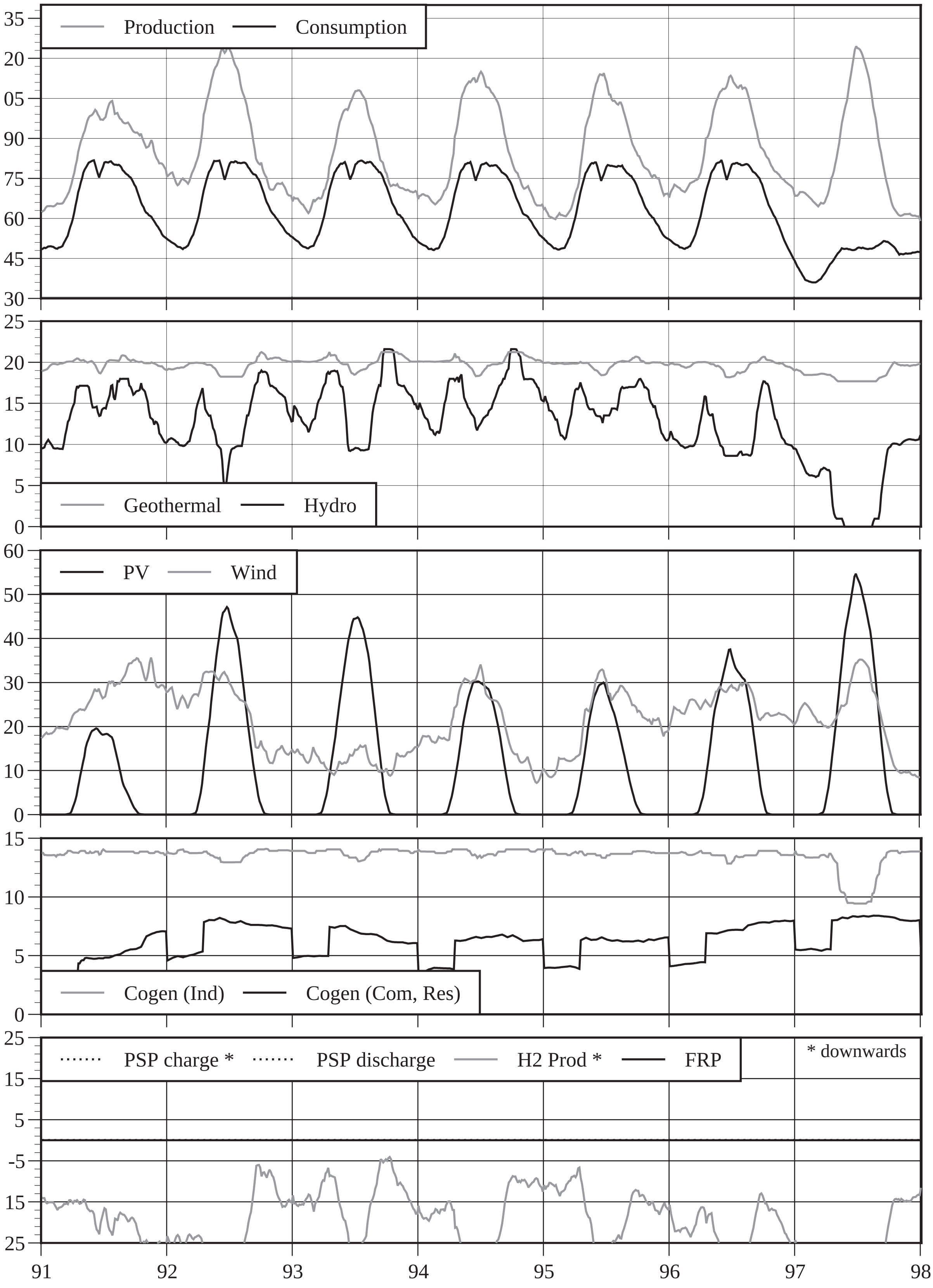


Figure 92 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 14. Source: ERJ.

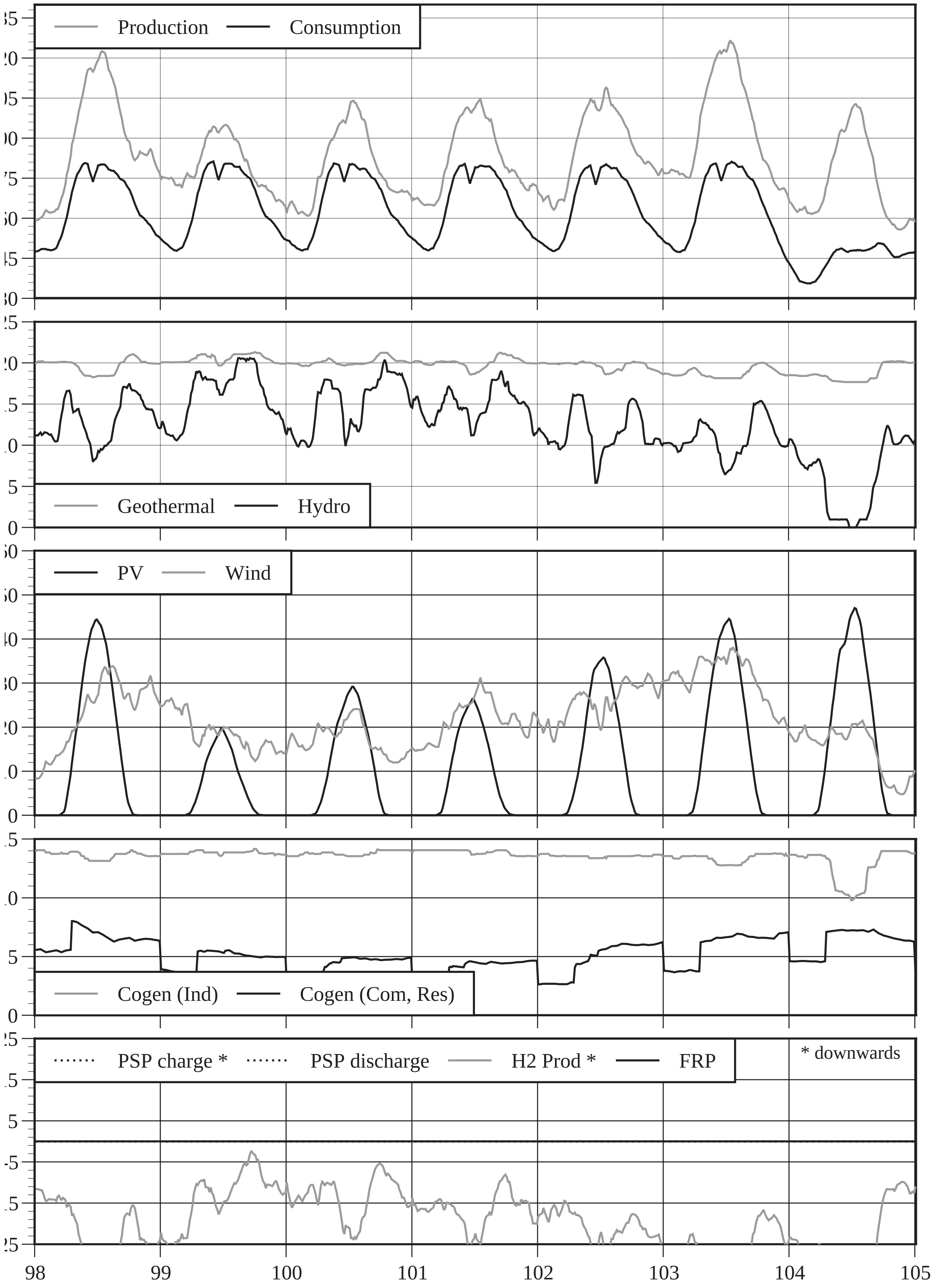


Figure 93 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 15. Source: ERJ.

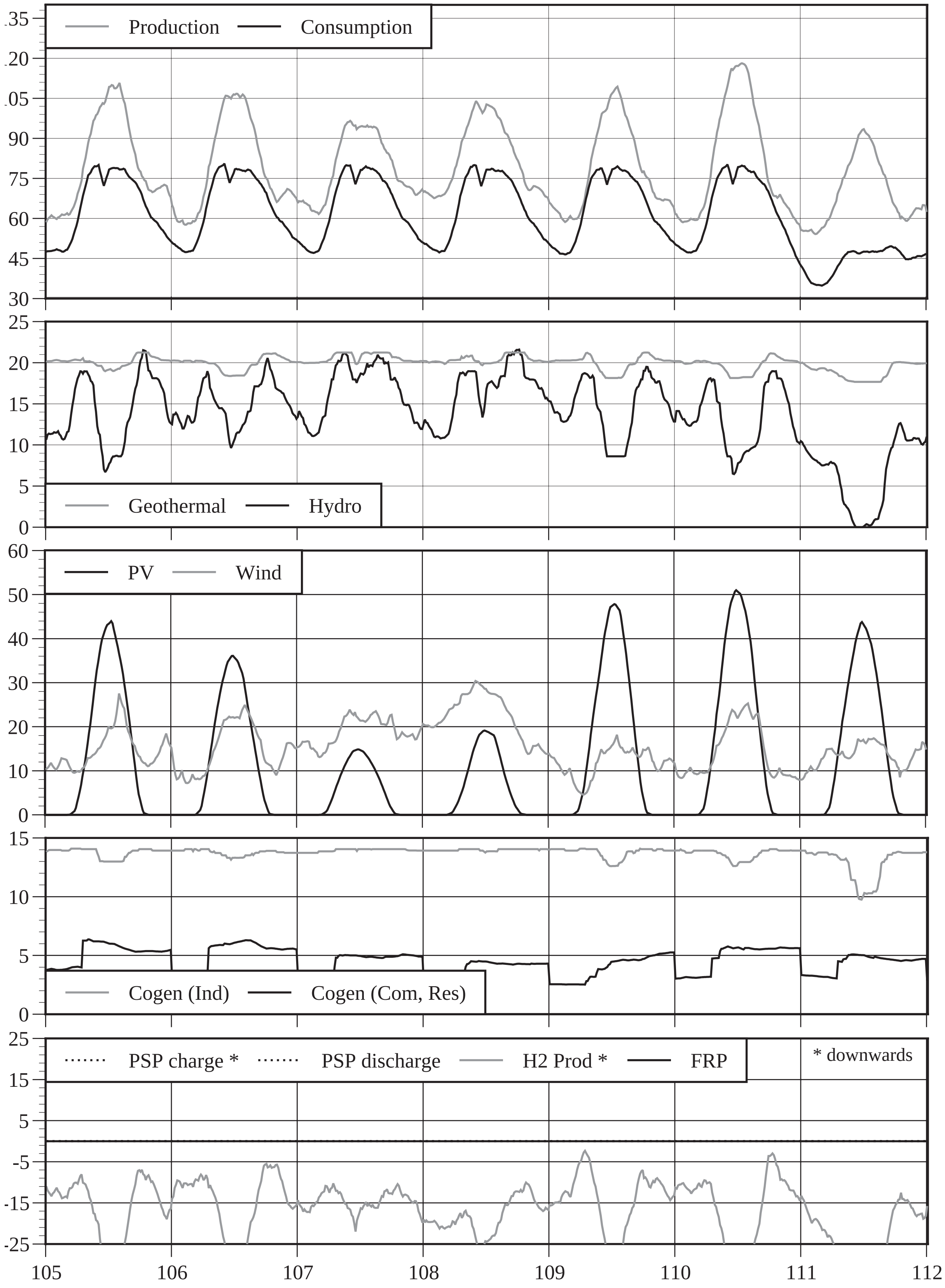


Figure 94 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 16. Source: ERJ.

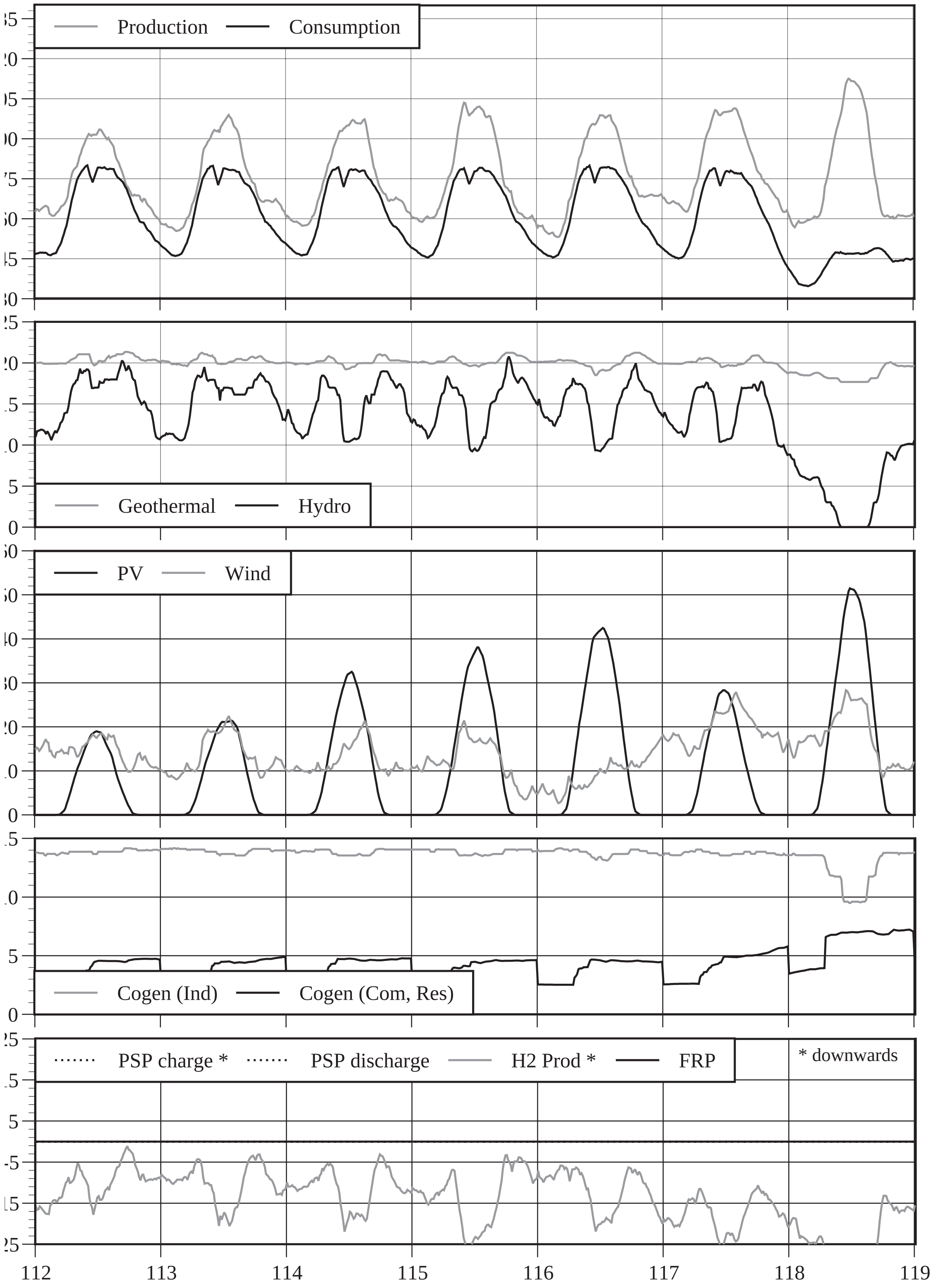


Figure 95 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 17. Source: ERJ.

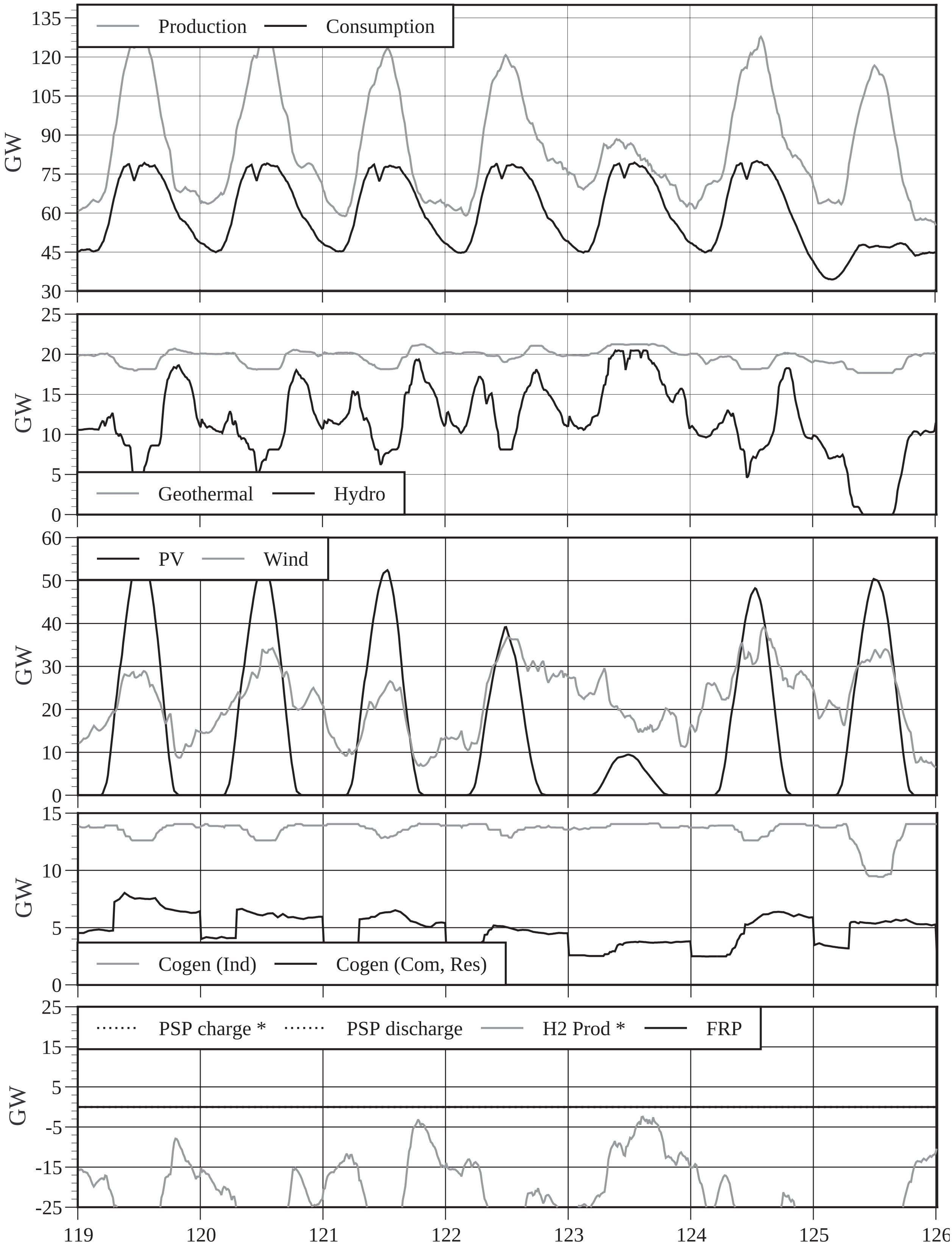


Figure 96 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 18. Source: ERJ.

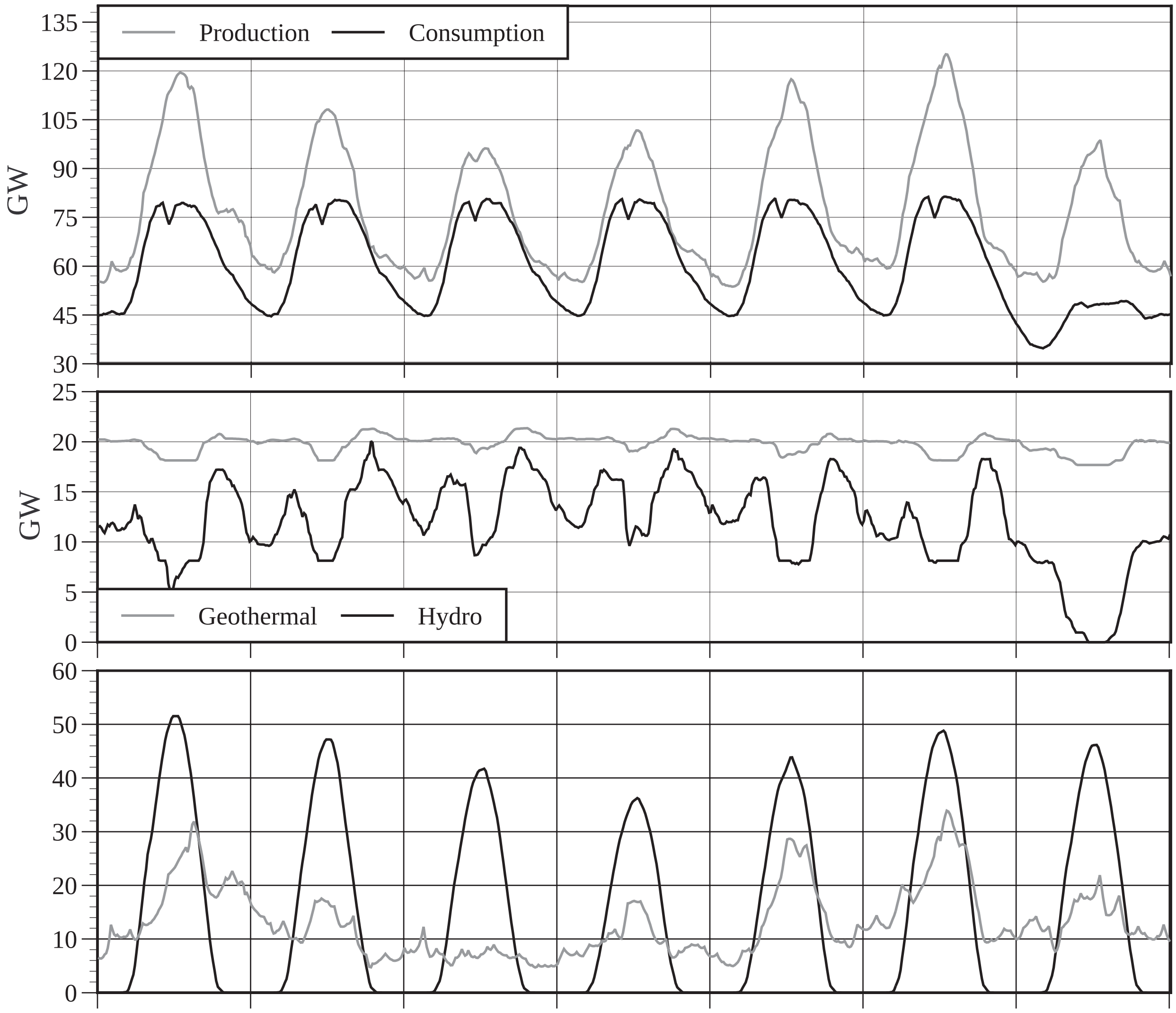


Figure 97 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 19. Source: ERJ.

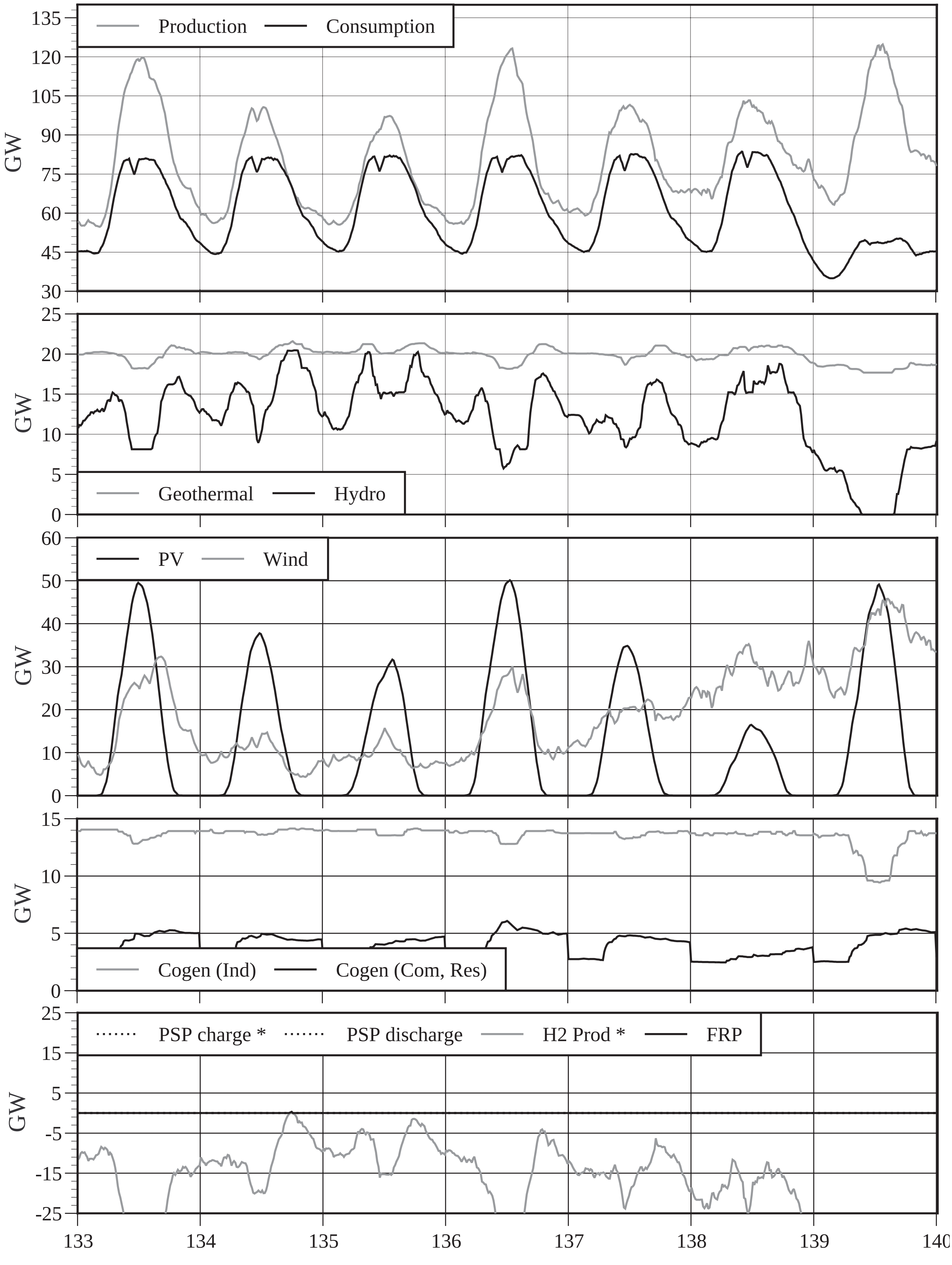


Figure 98 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 20. Source: ERJ.

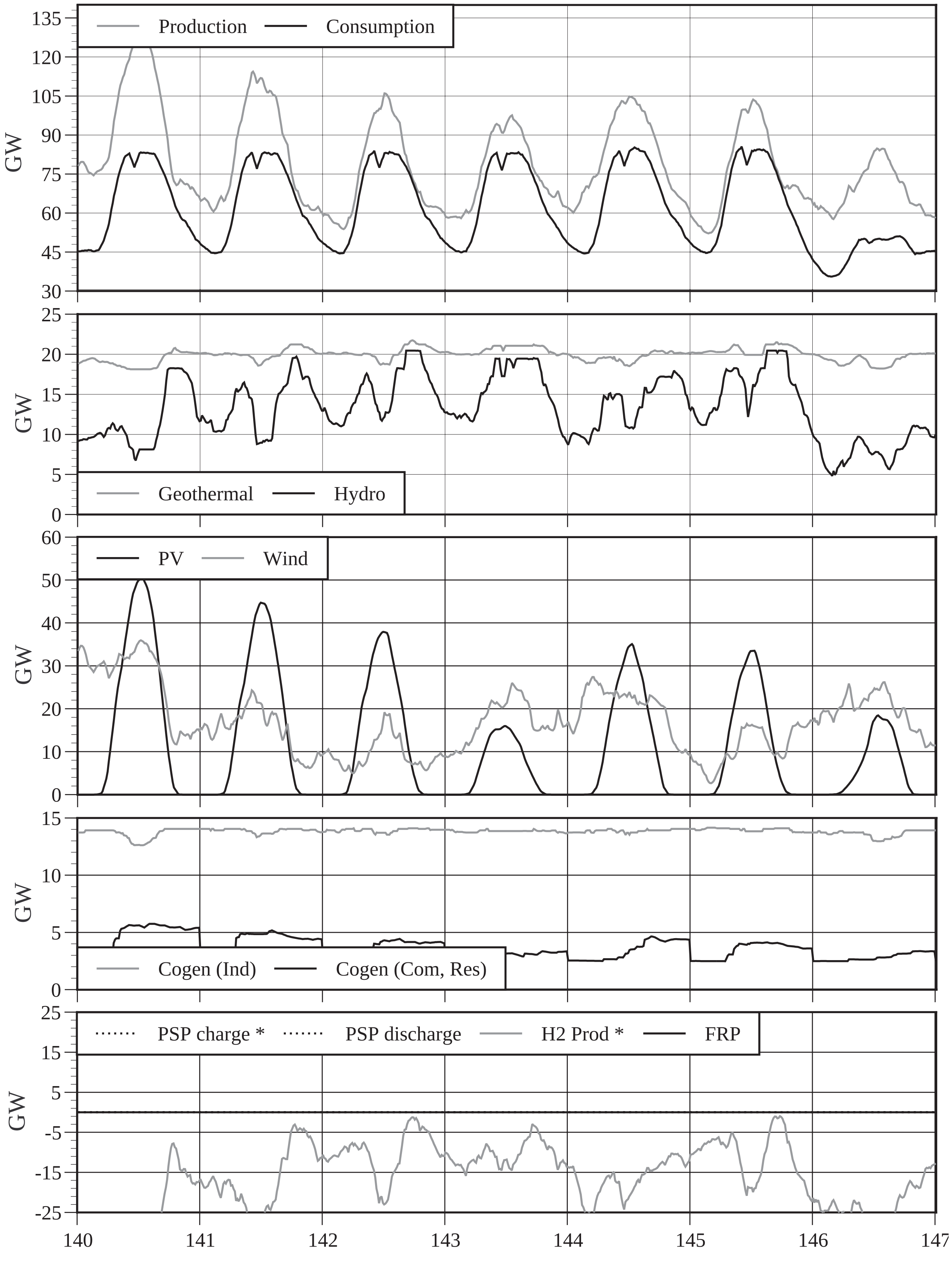


Figure 99 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 21. Source: ERJ.

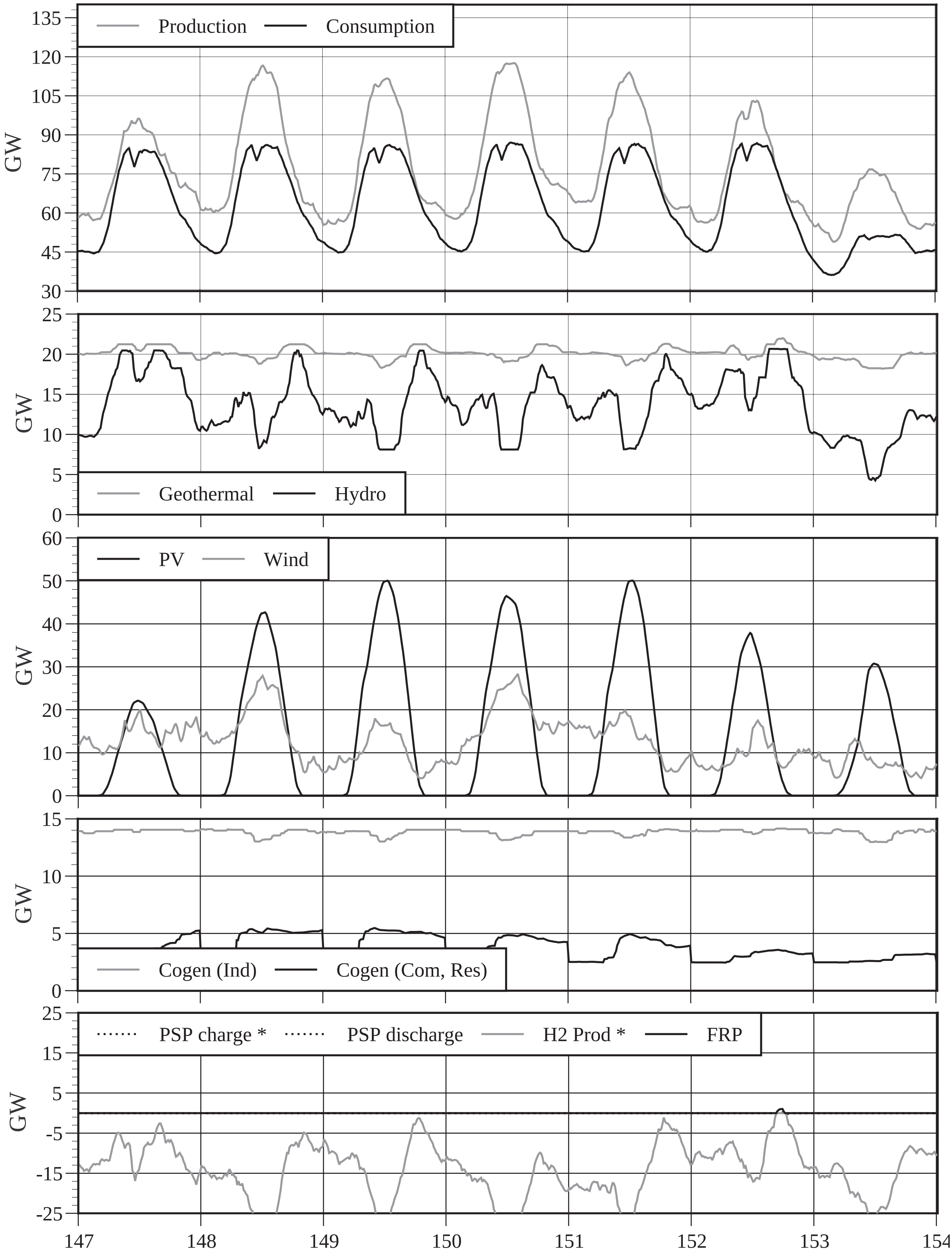


Figure 100 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 22. Source: ERJ.

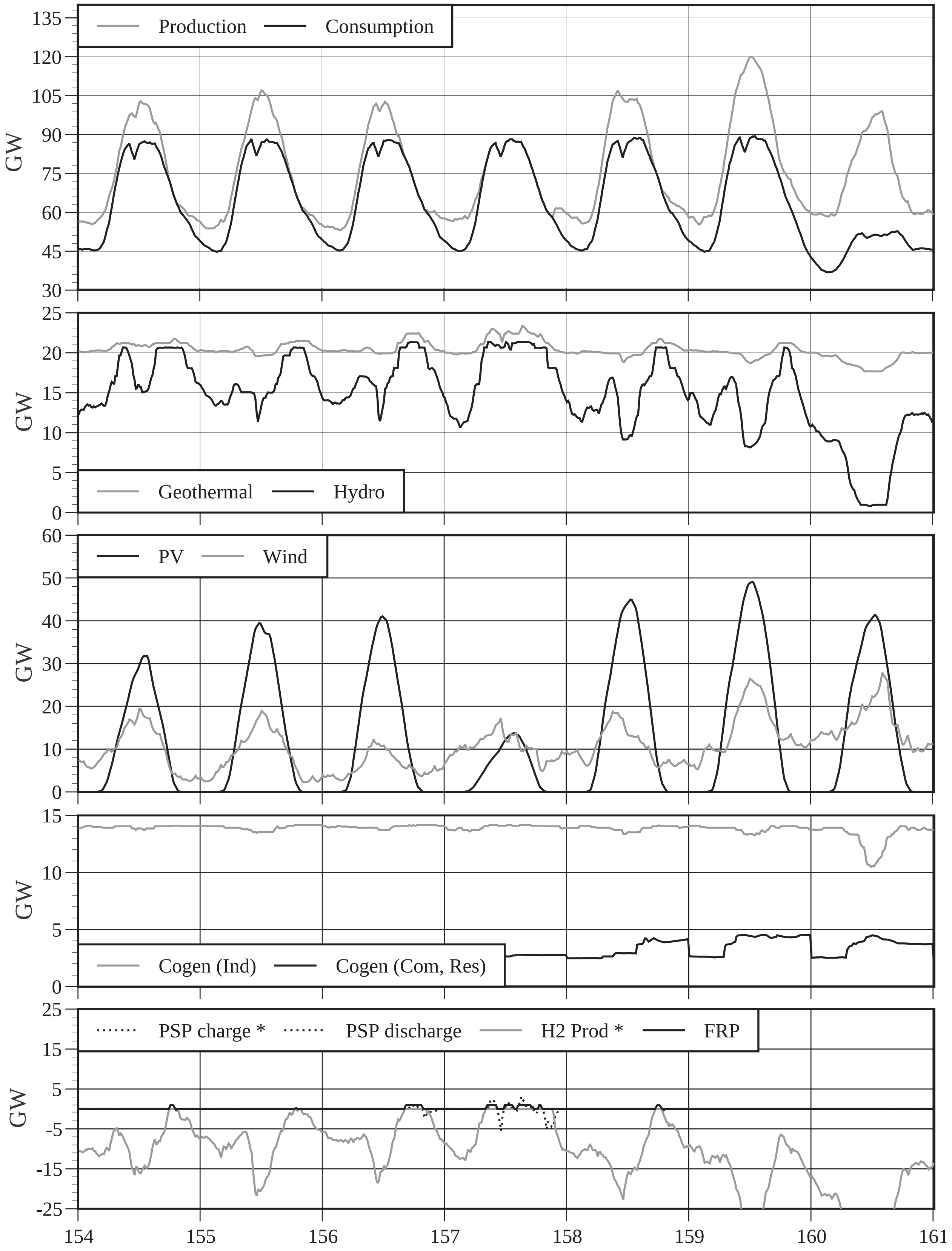


Figure 101 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 23. Source: ERJ.

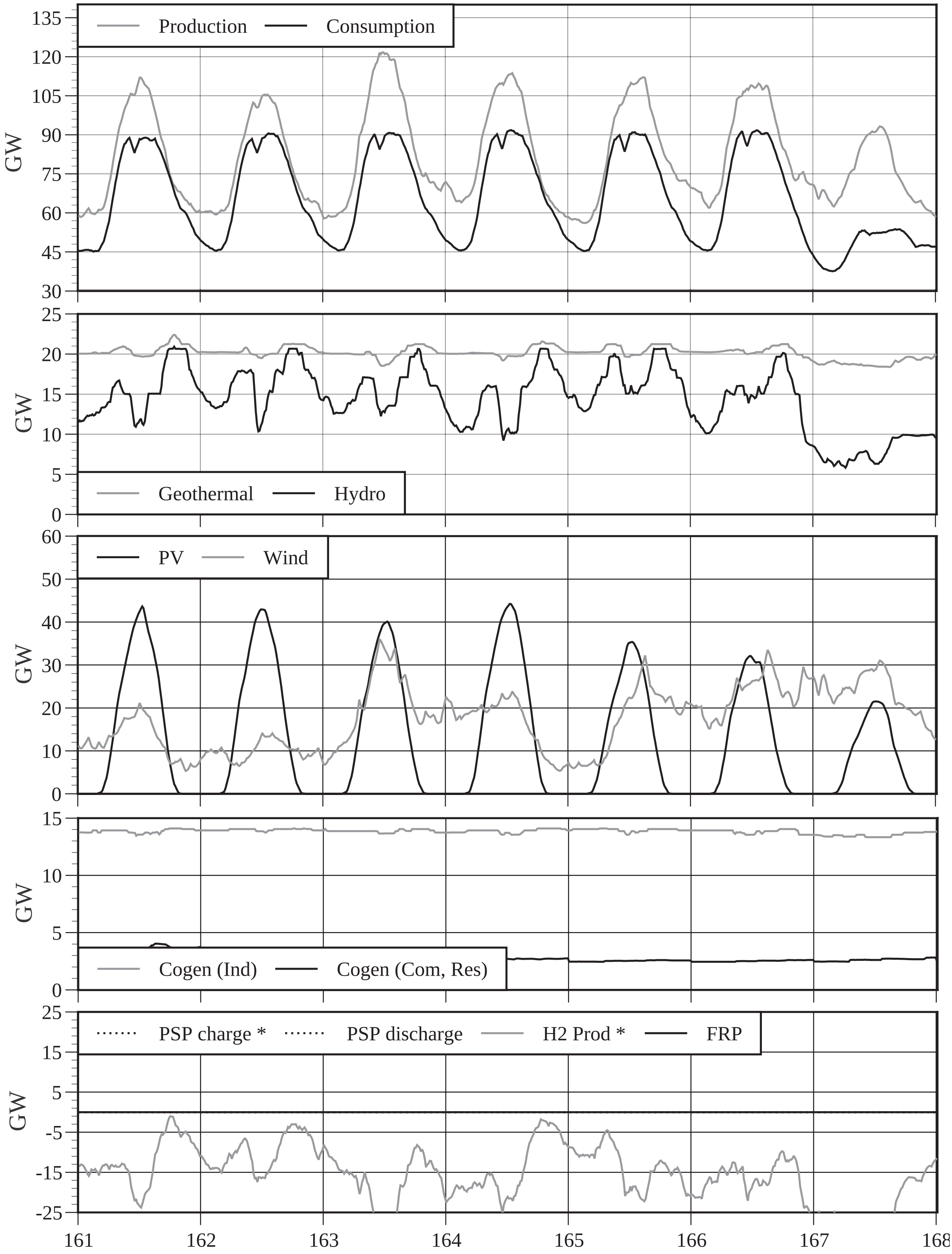


Figure 102 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 24. Source: ERJ.

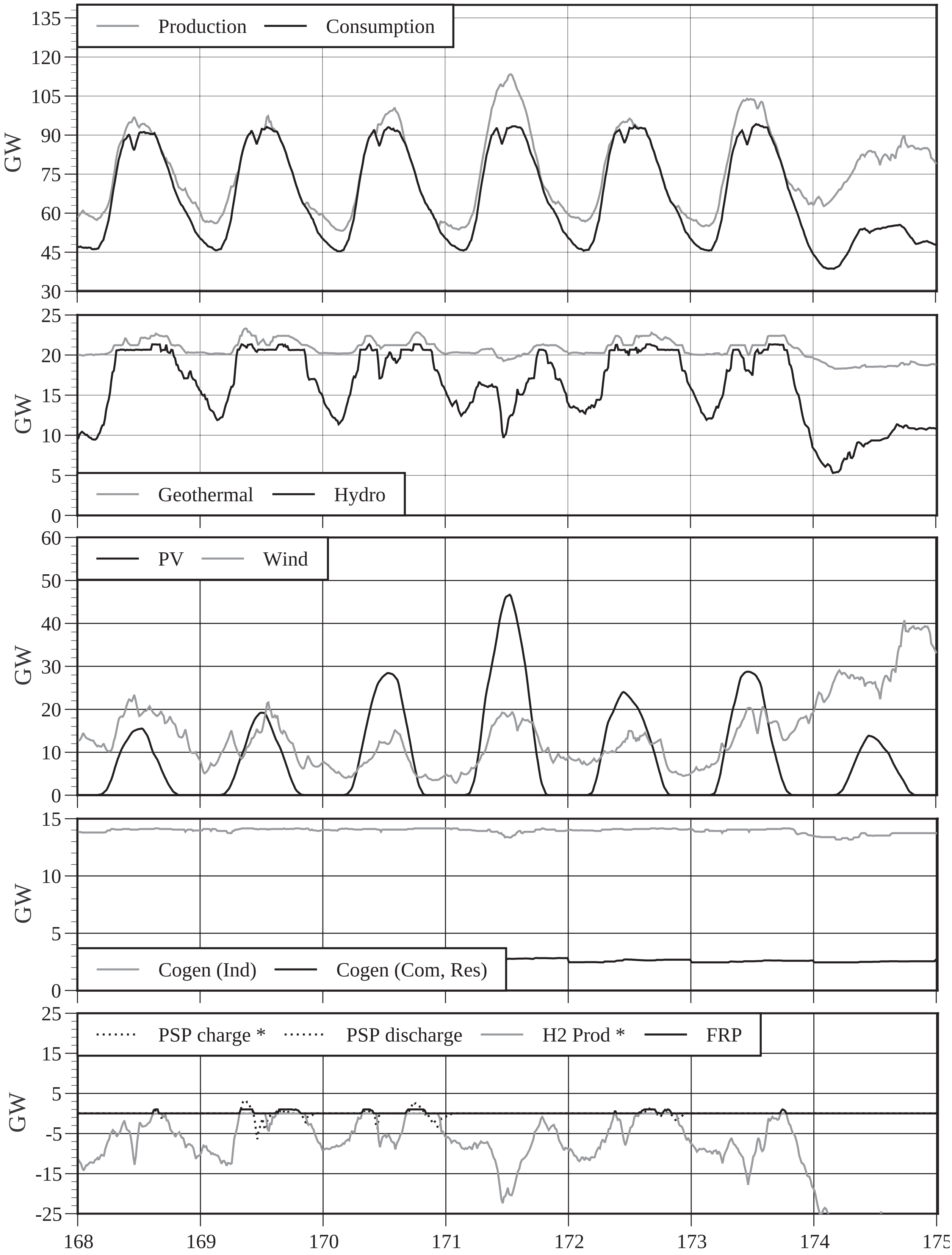


Figure 103 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 25. Source: ERJ.

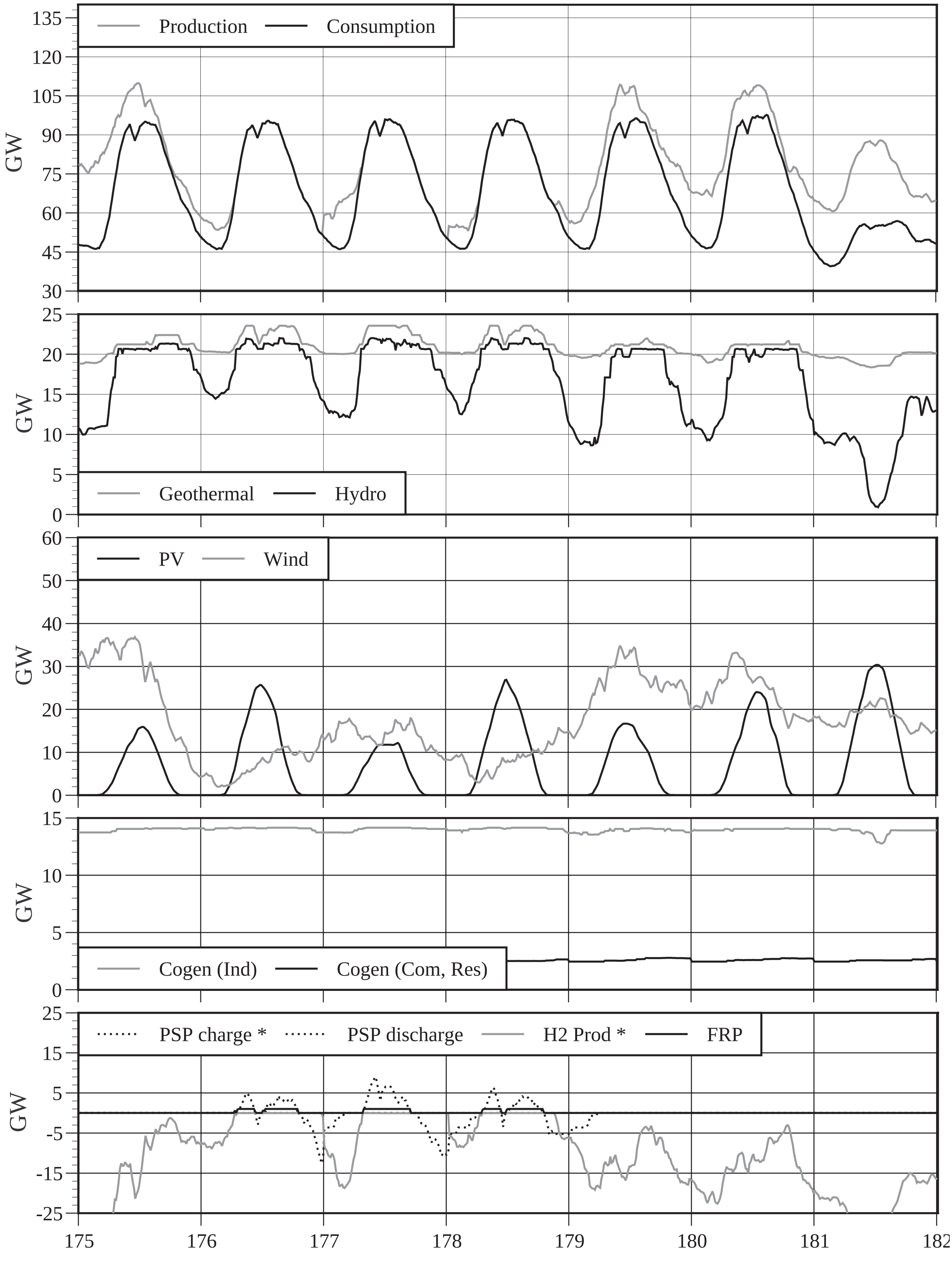


Figure 104 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 26. Source: ERJ.

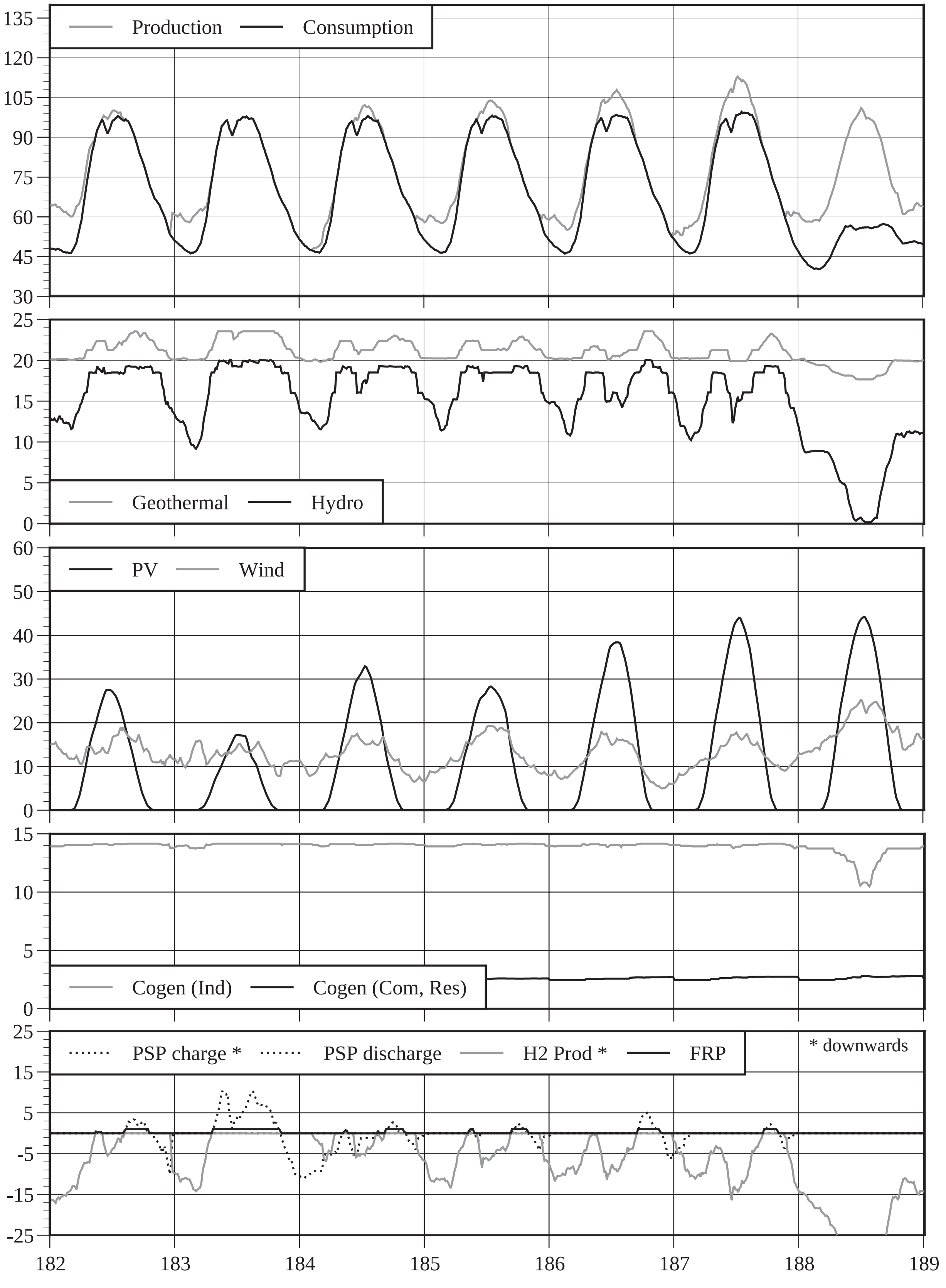


Figure 105 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 27. Source: ERJ.

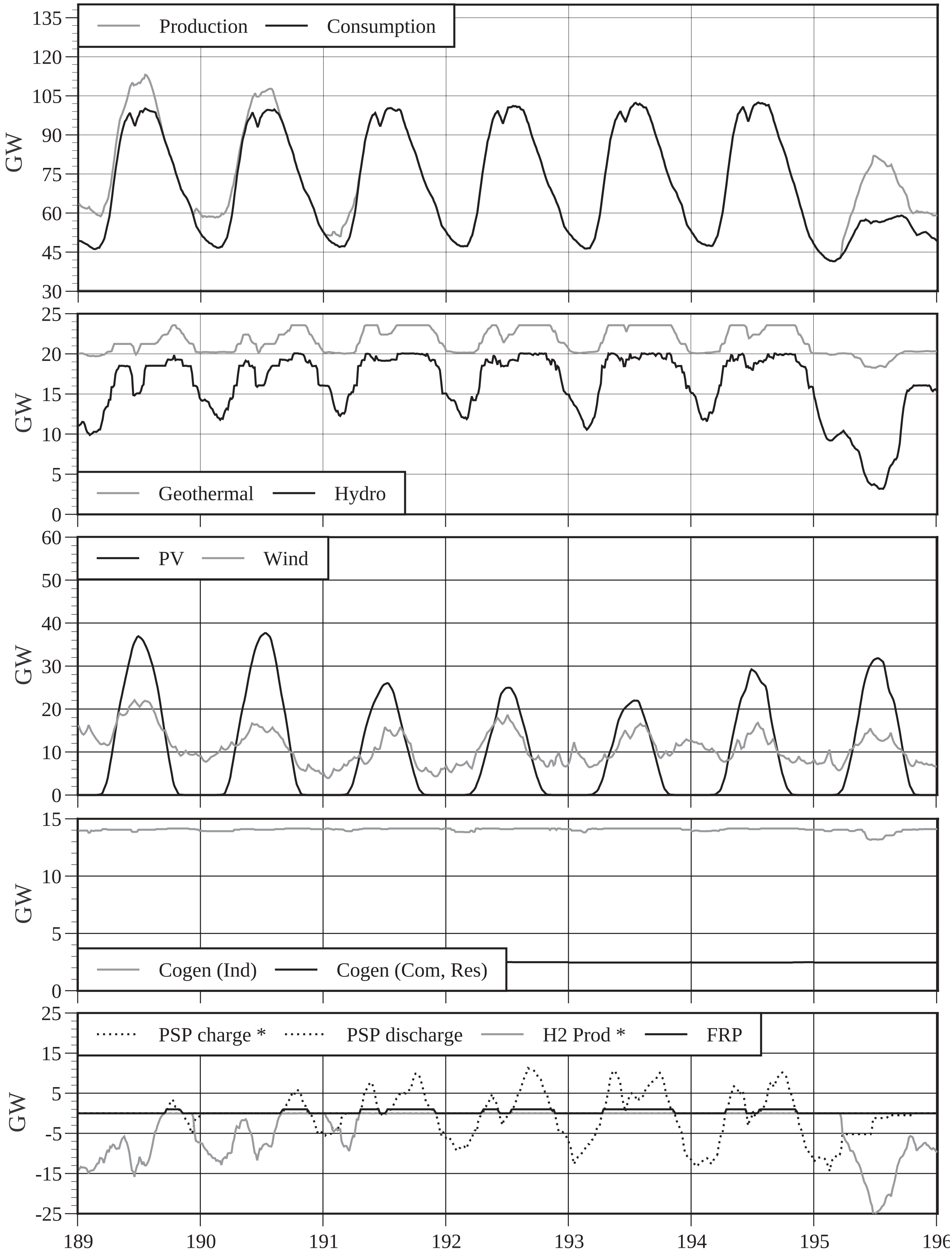


Figure 106 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 28. Source: ERJ.

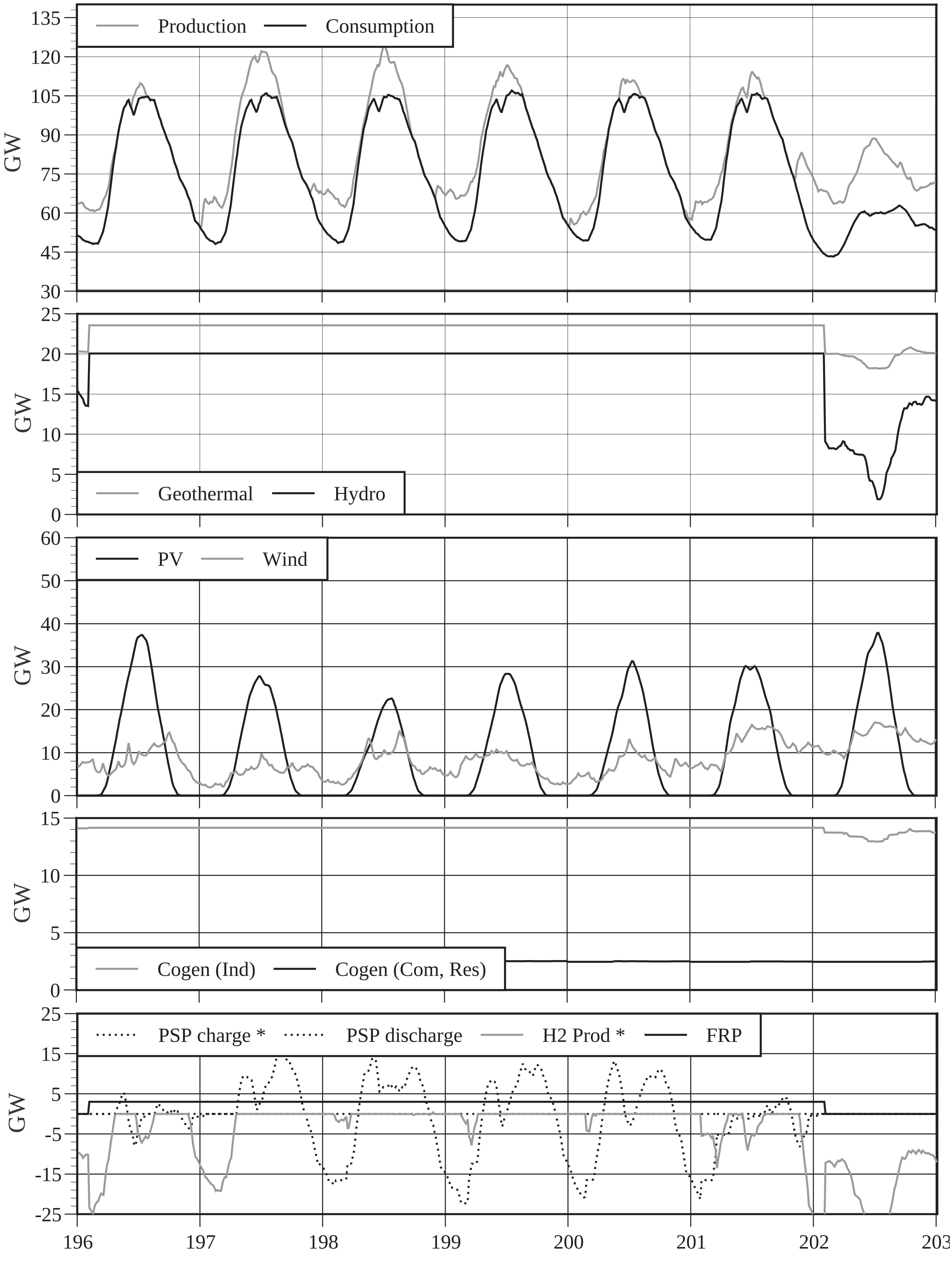


Figure 107 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 29. Source: ERJ.

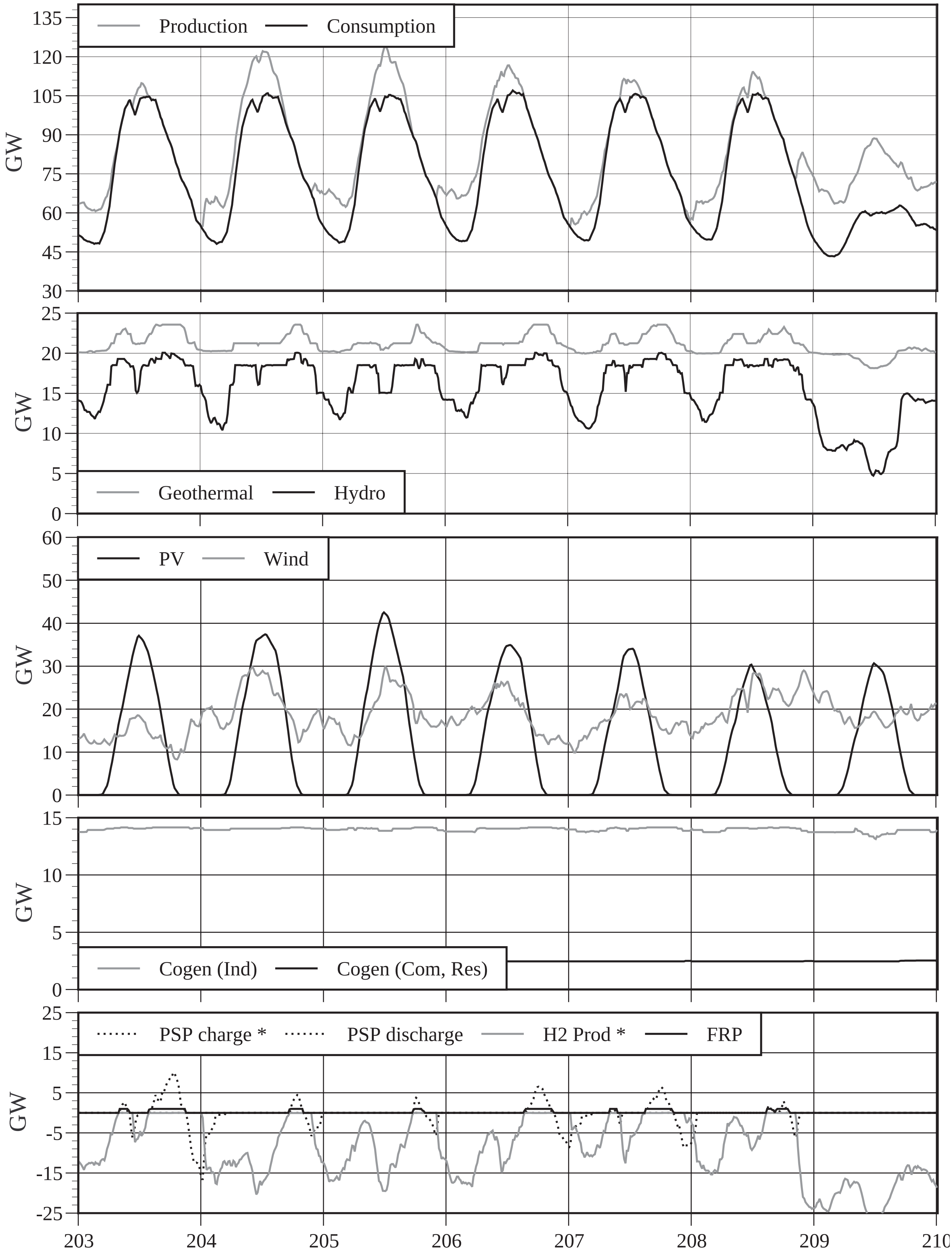


Figure 108 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 30. Source: ERJ.

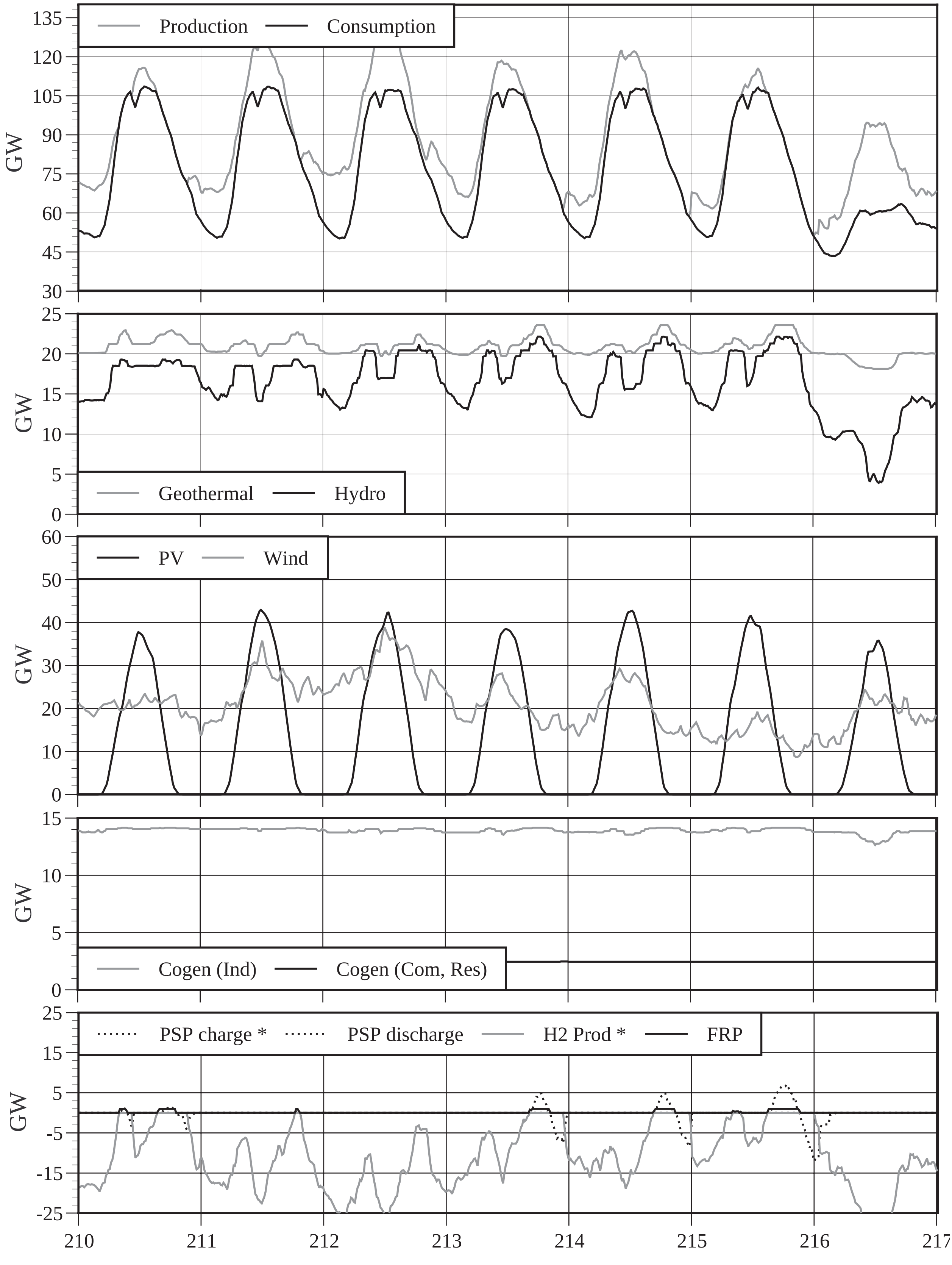


Figure 109 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 31. Source: ERJ.

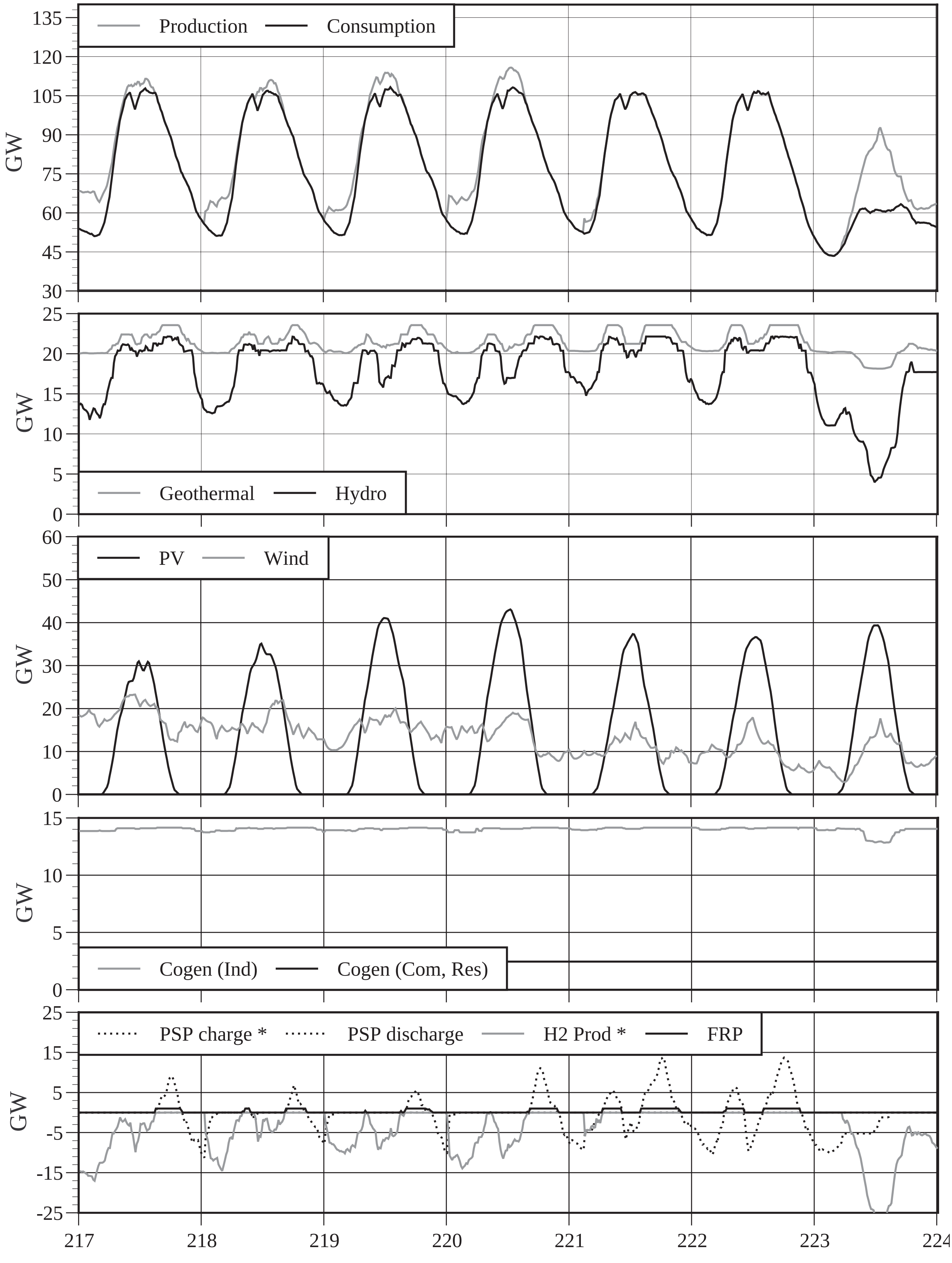


Figure 110 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 32. Source: ERJ.

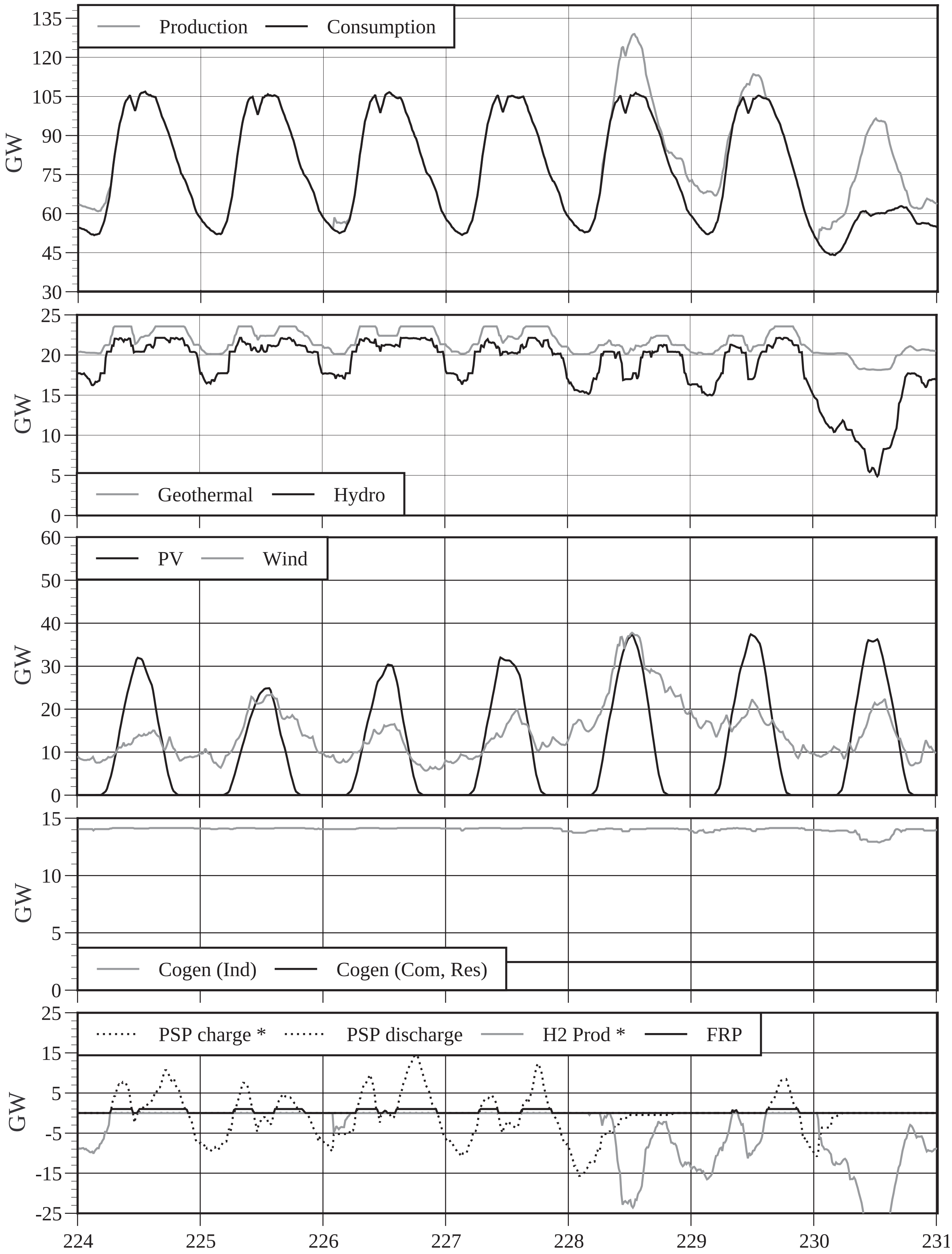


Figure 111 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 33. Source: ERJ.

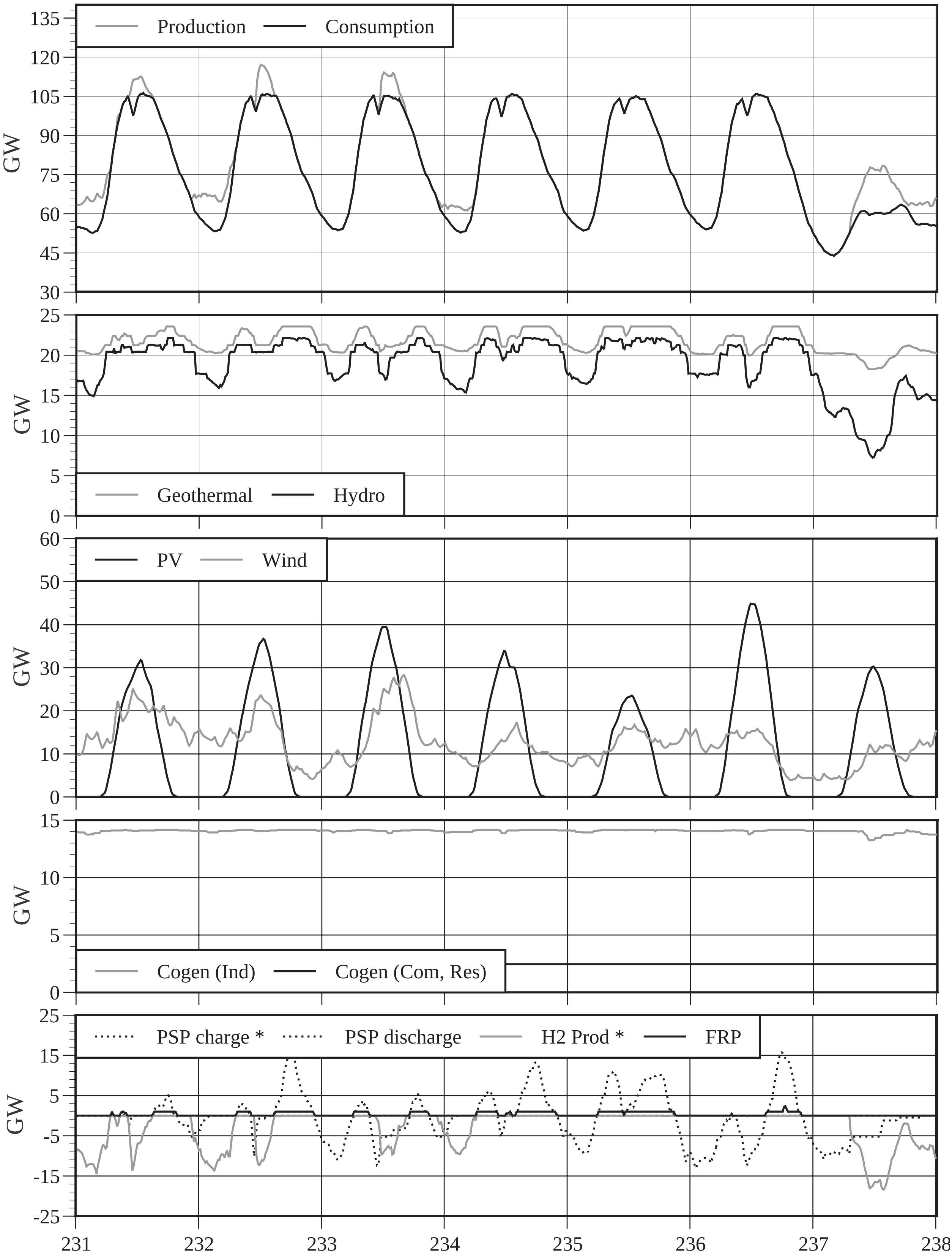


Figure 112 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 34. Source: ERJ.

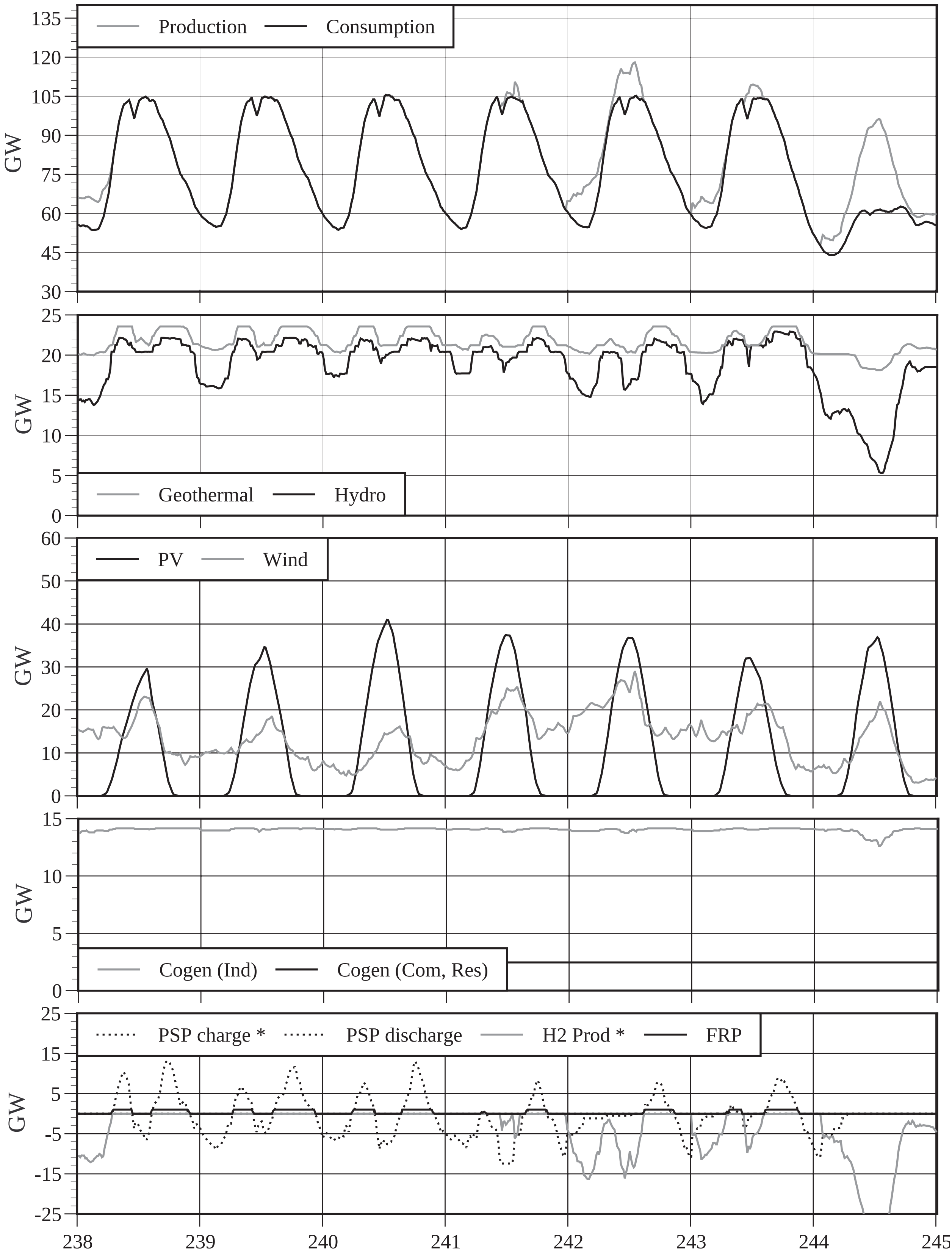


Figure 113 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 35. Source: ERJ.

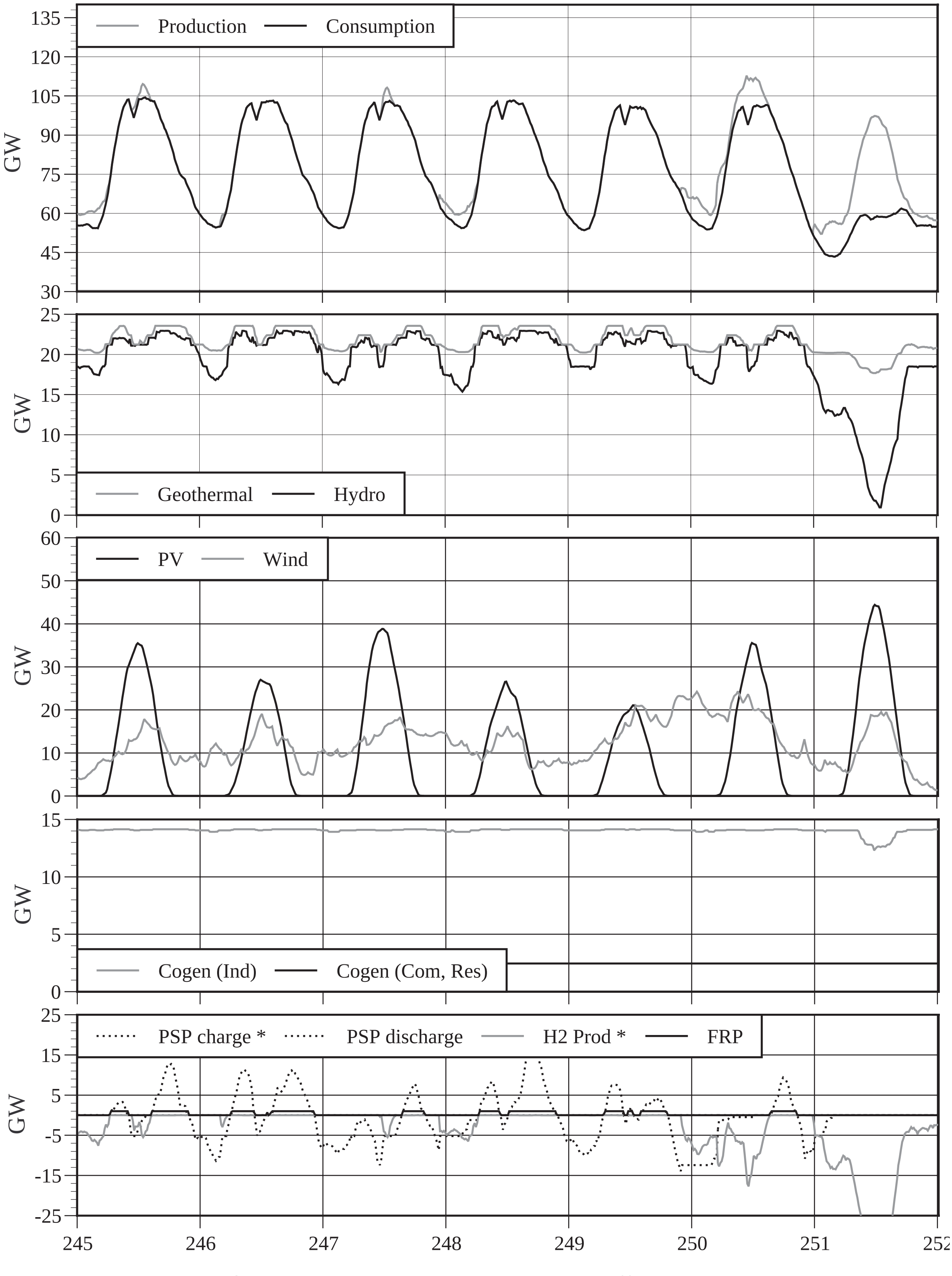


Figure 114 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 36. Source: ERJ.

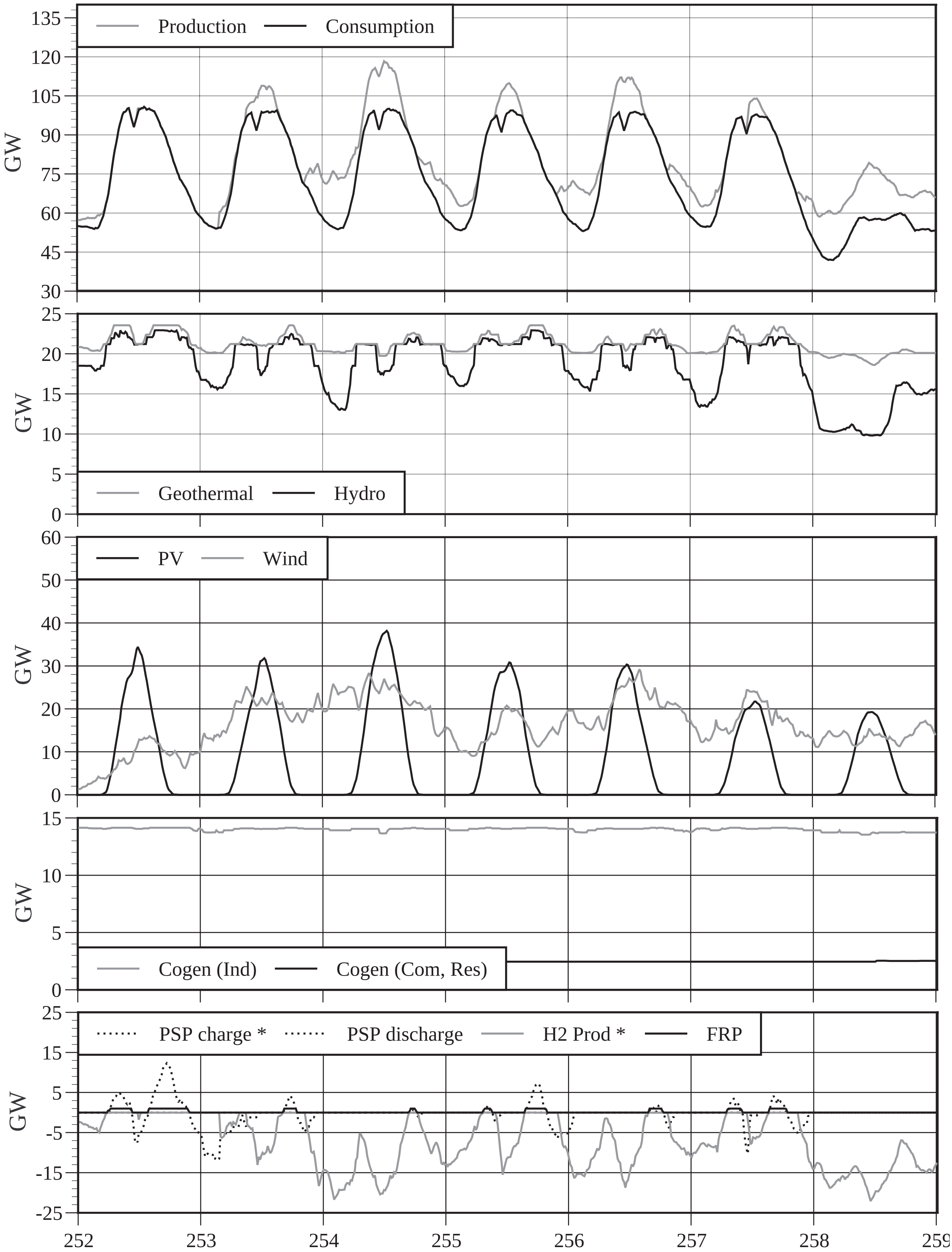


Figure 115 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 37. Source: ERJ.

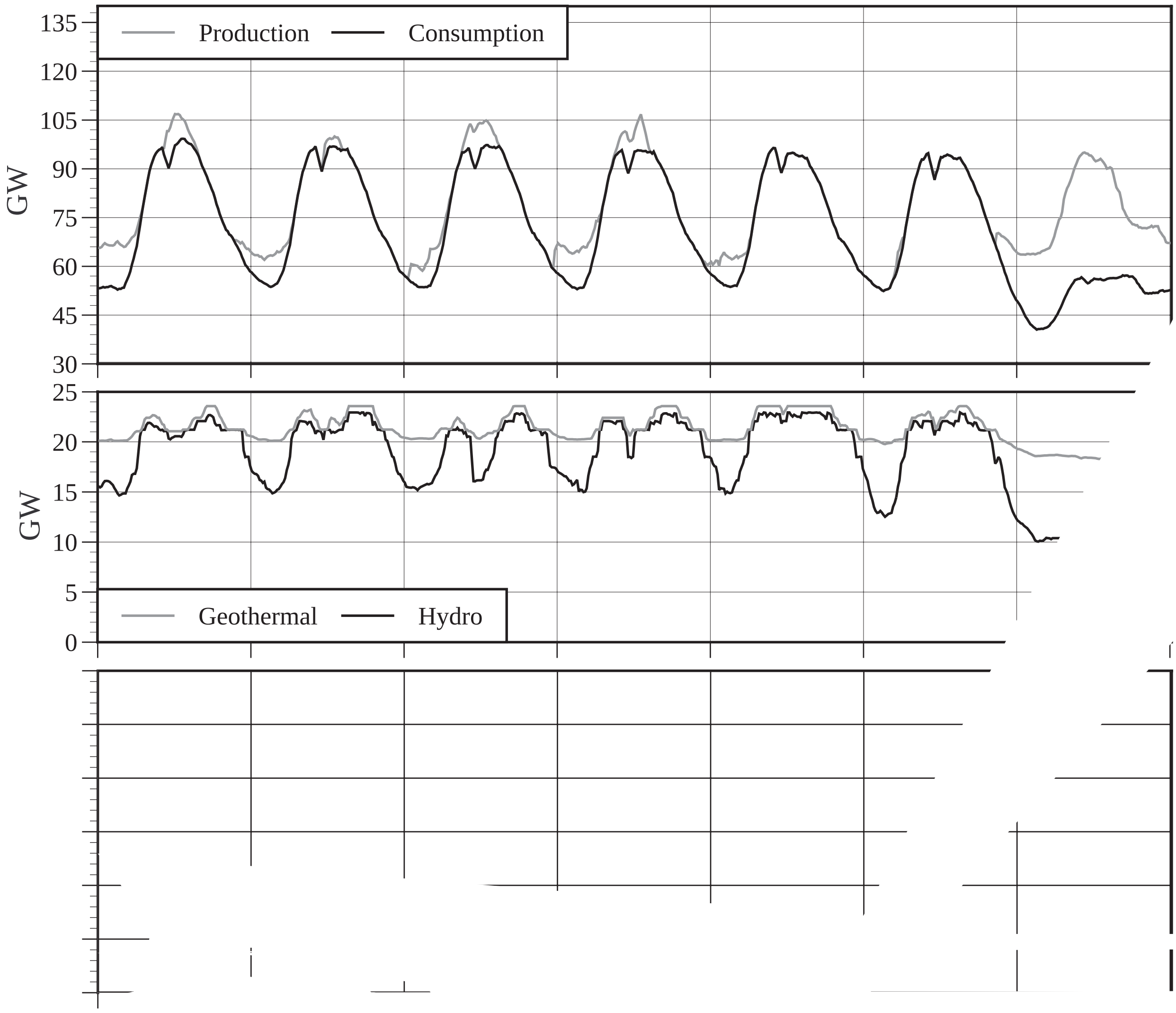


Figure 116 : The figure shows the energy y different technologies, the total demand and the storage of electrical surplus in n or pumped hydropower in Week 38. Source: ERJ.

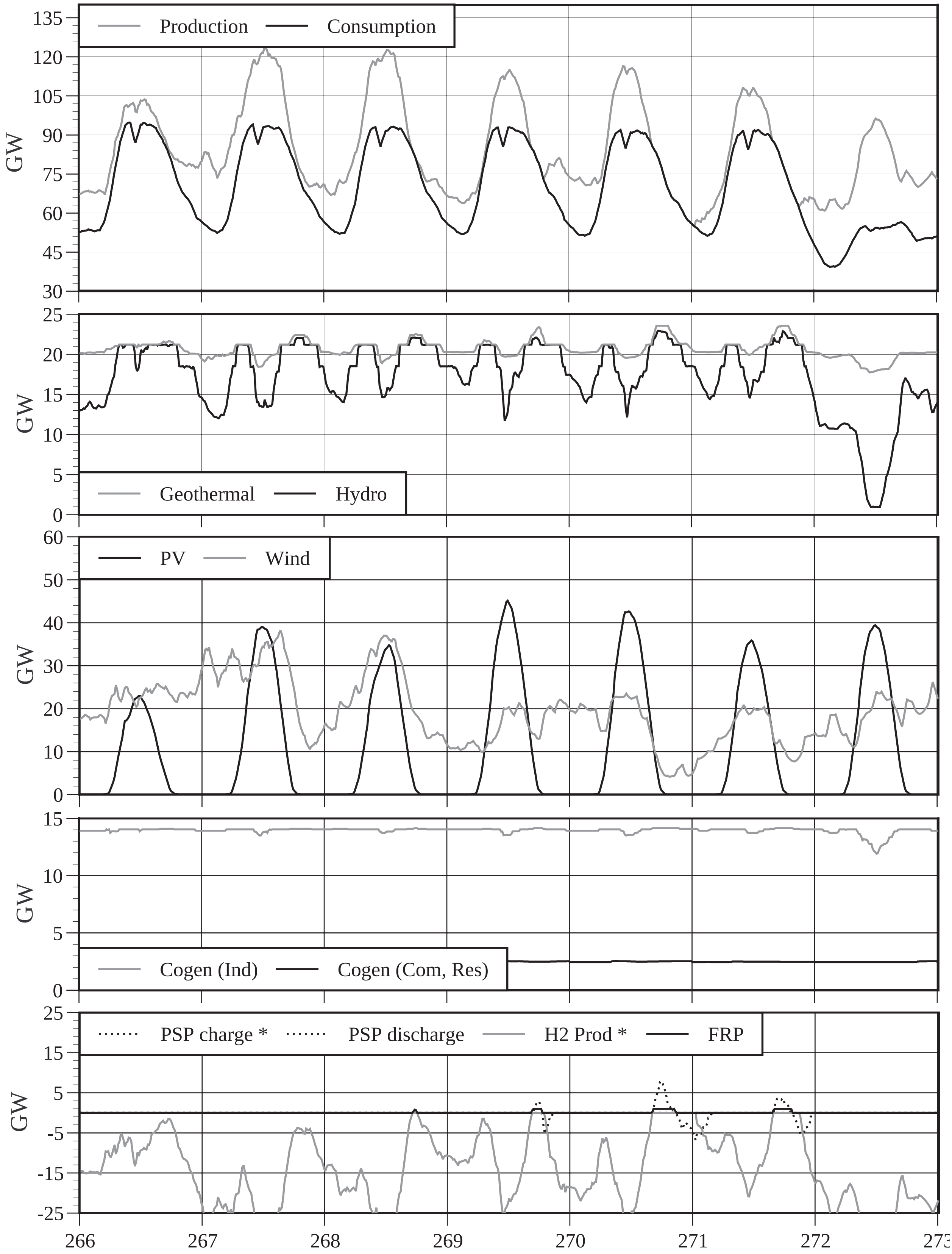


Figure 117 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 39. Source: ERJ.

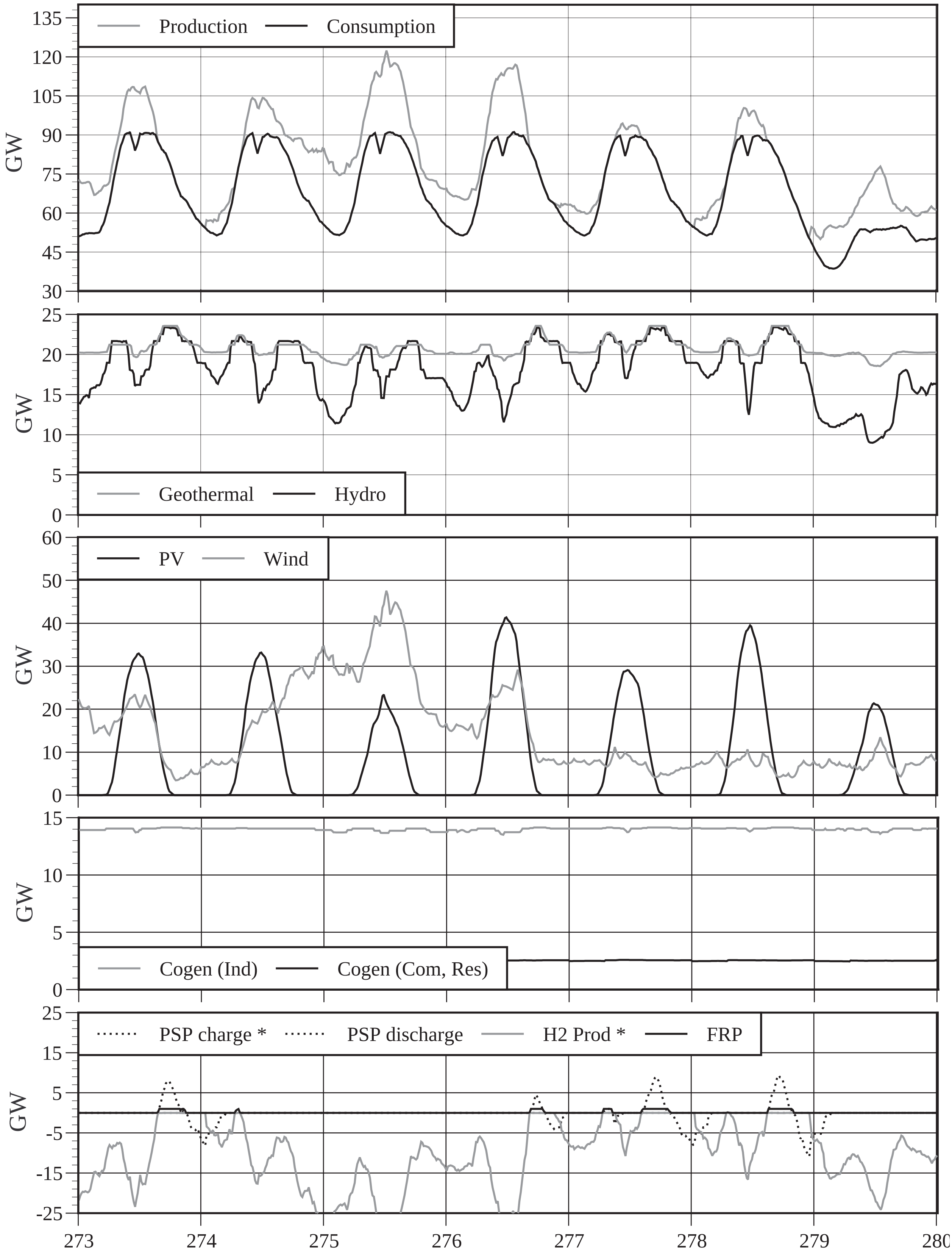


Figure 118 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 40. Source: ERJ.

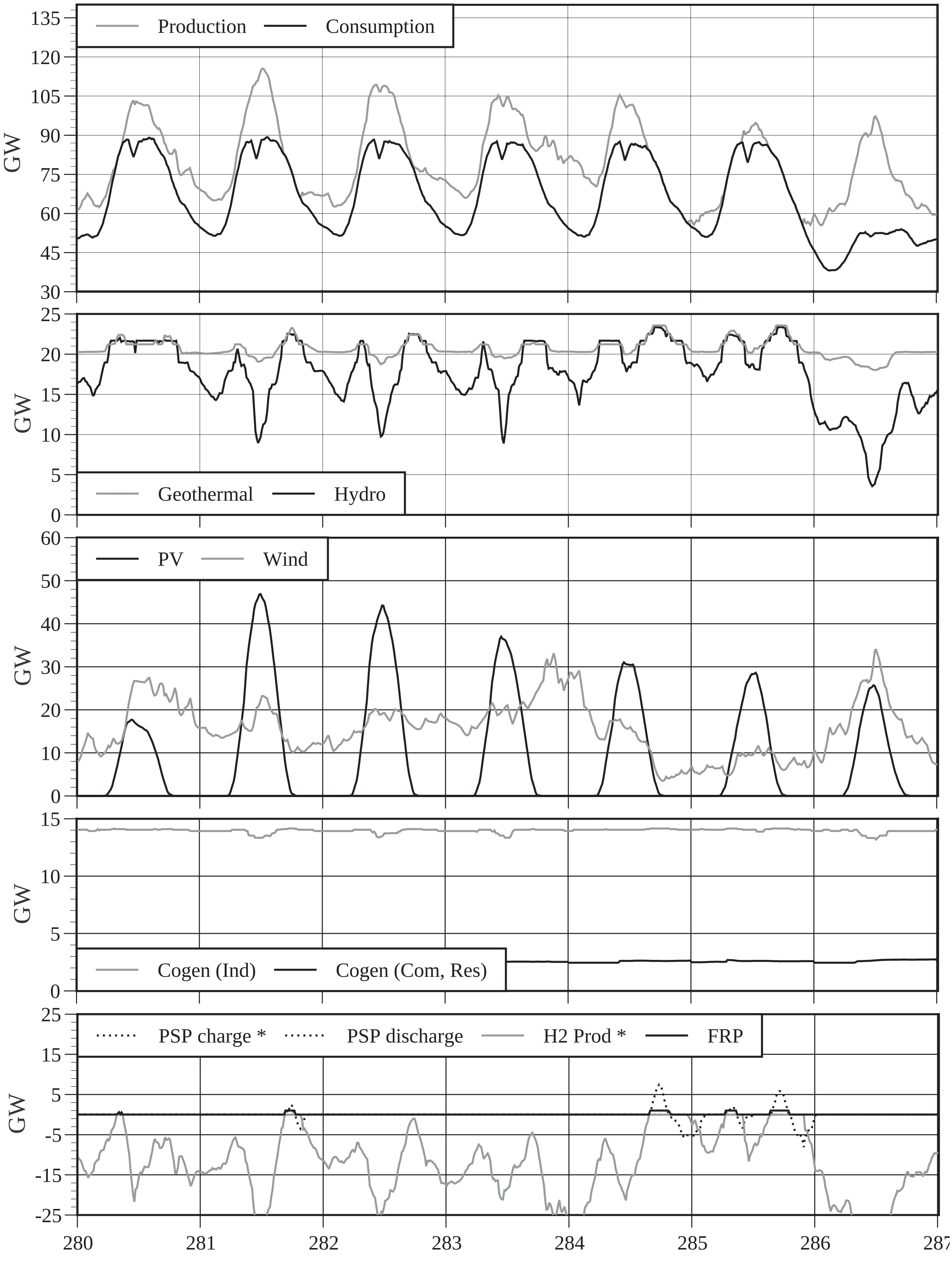


Figure 119 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 41. Source: ERJ.

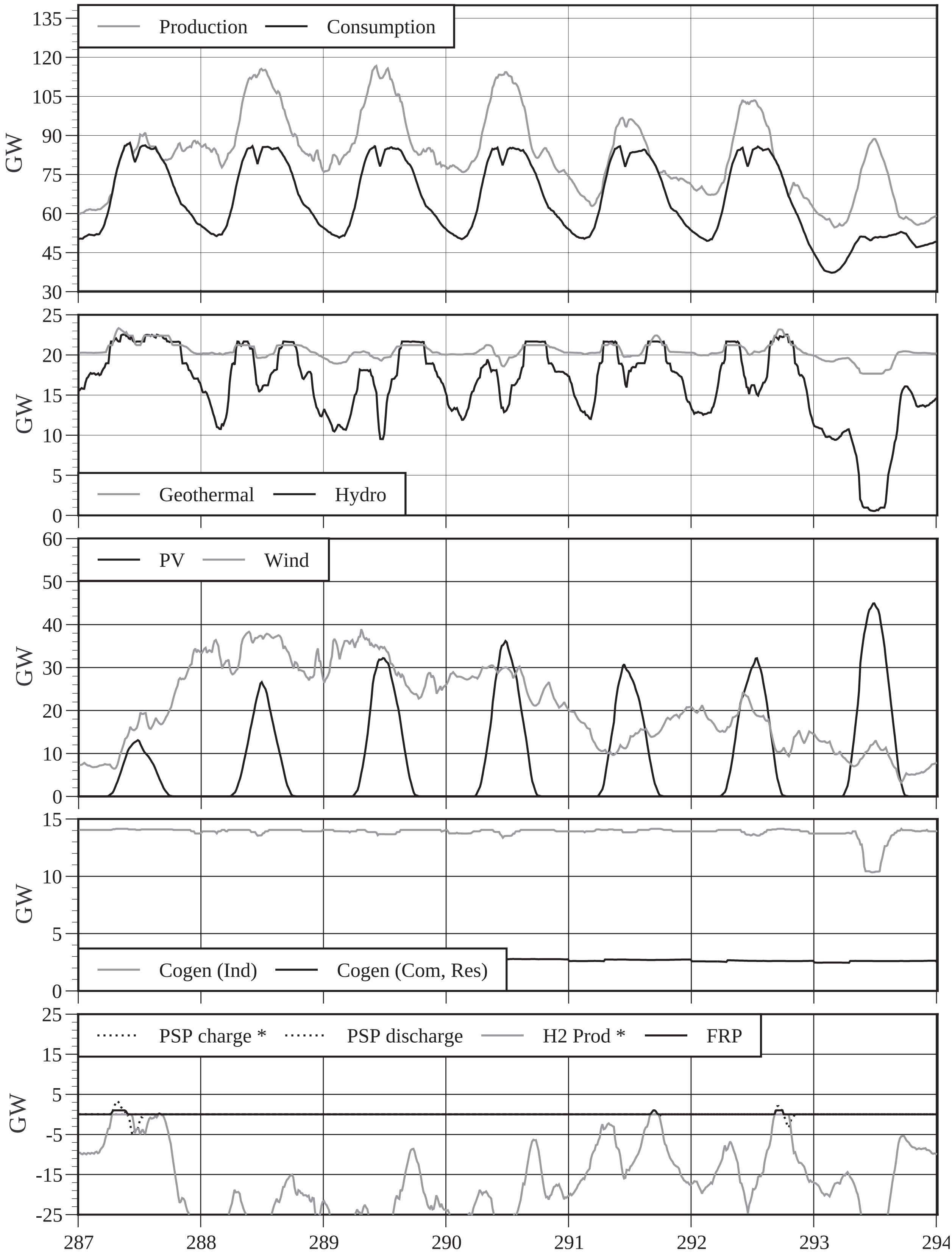


Figure 120 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 42. Source: ERJ.

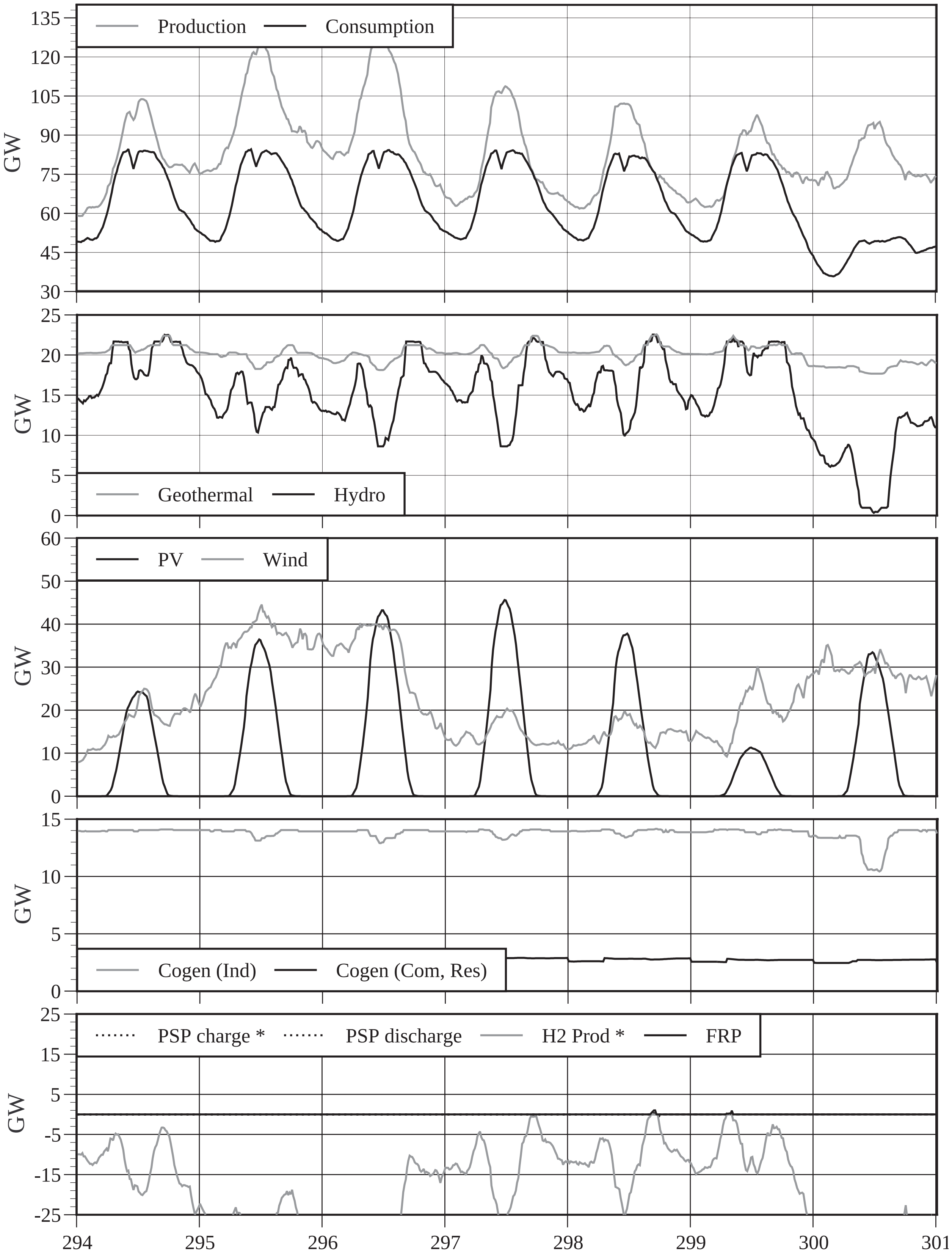


Figure 121 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 43. Source: ERJ.

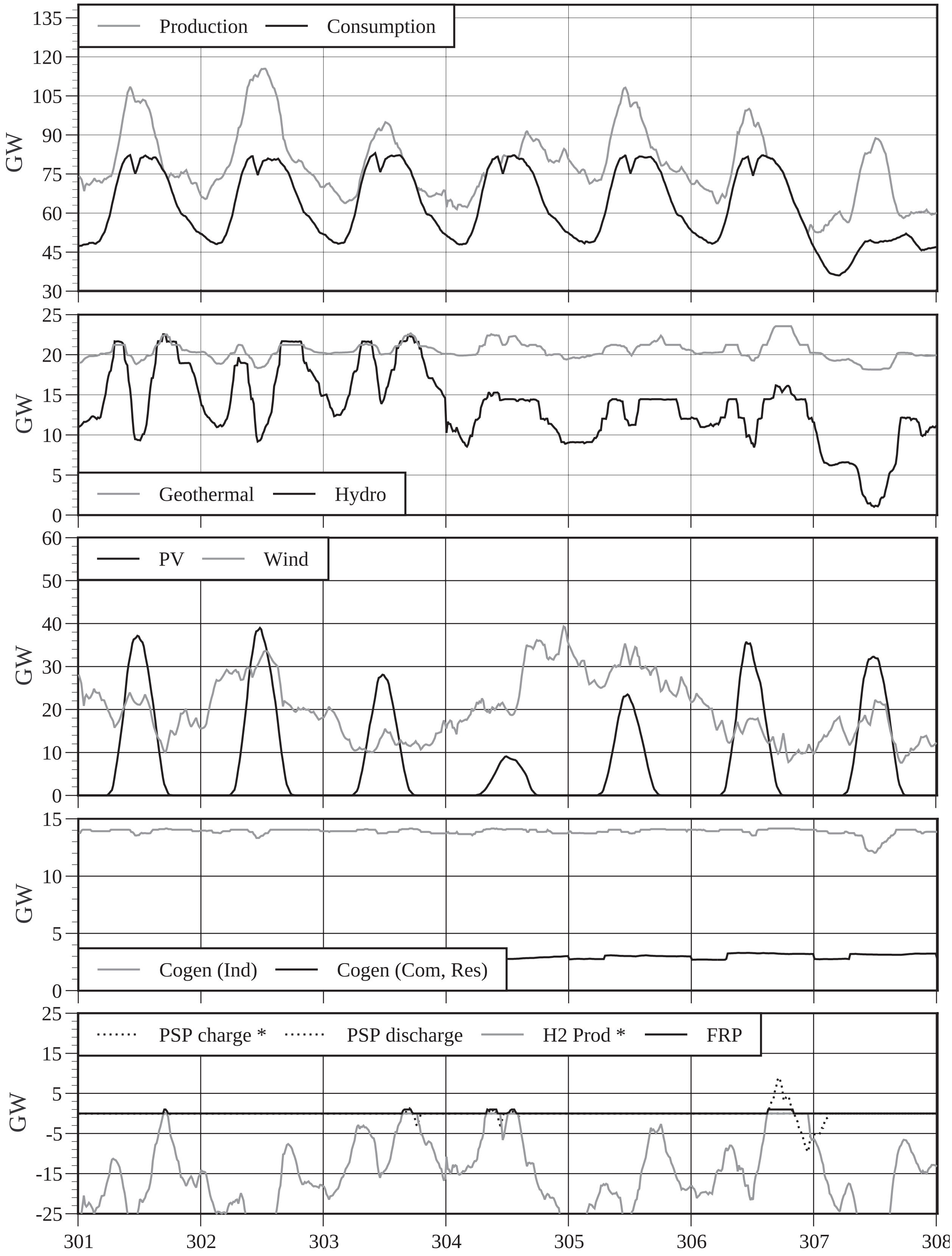


Figure 122 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 44. Source: ERJ.

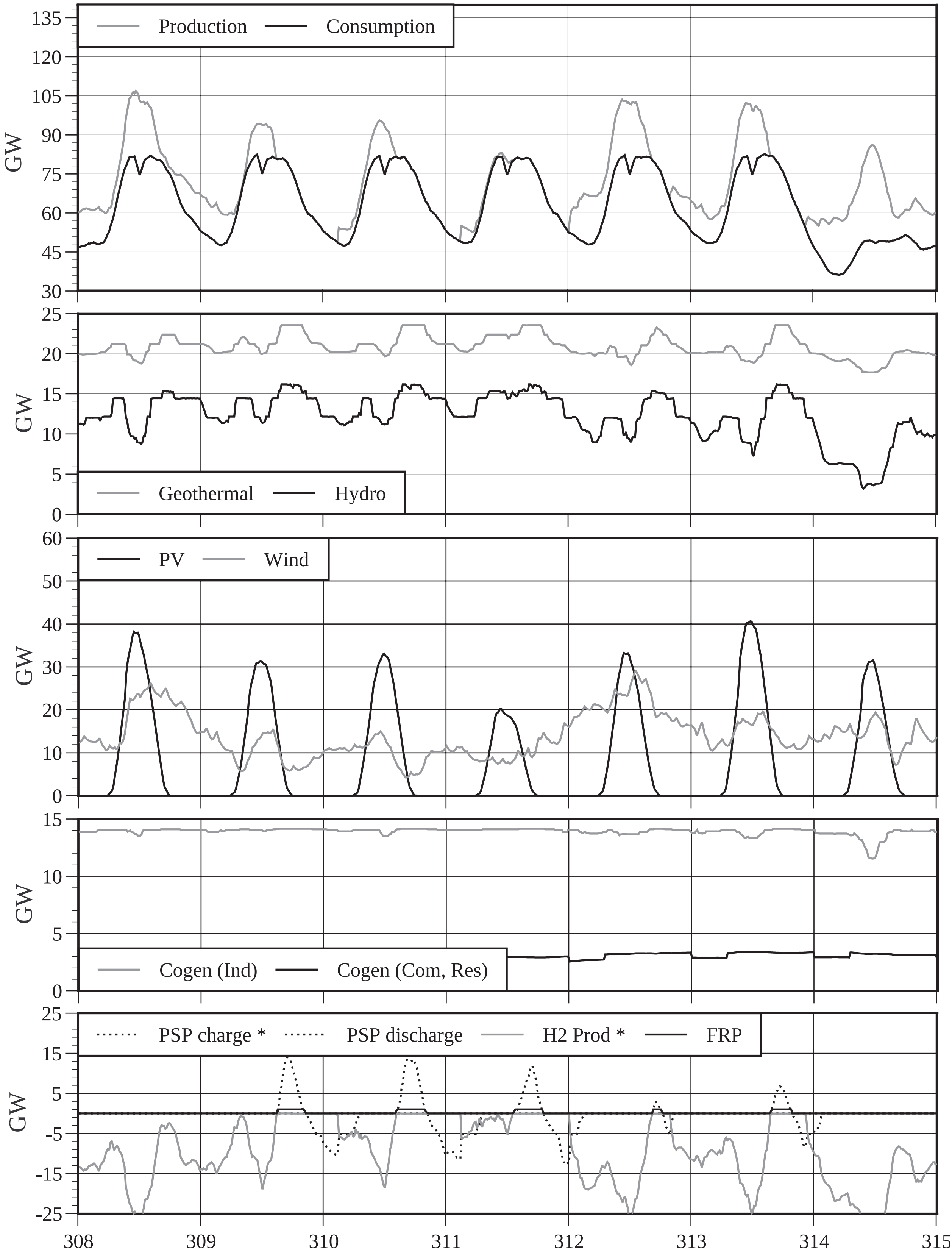


Figure 123 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 45. Source: ERJ.

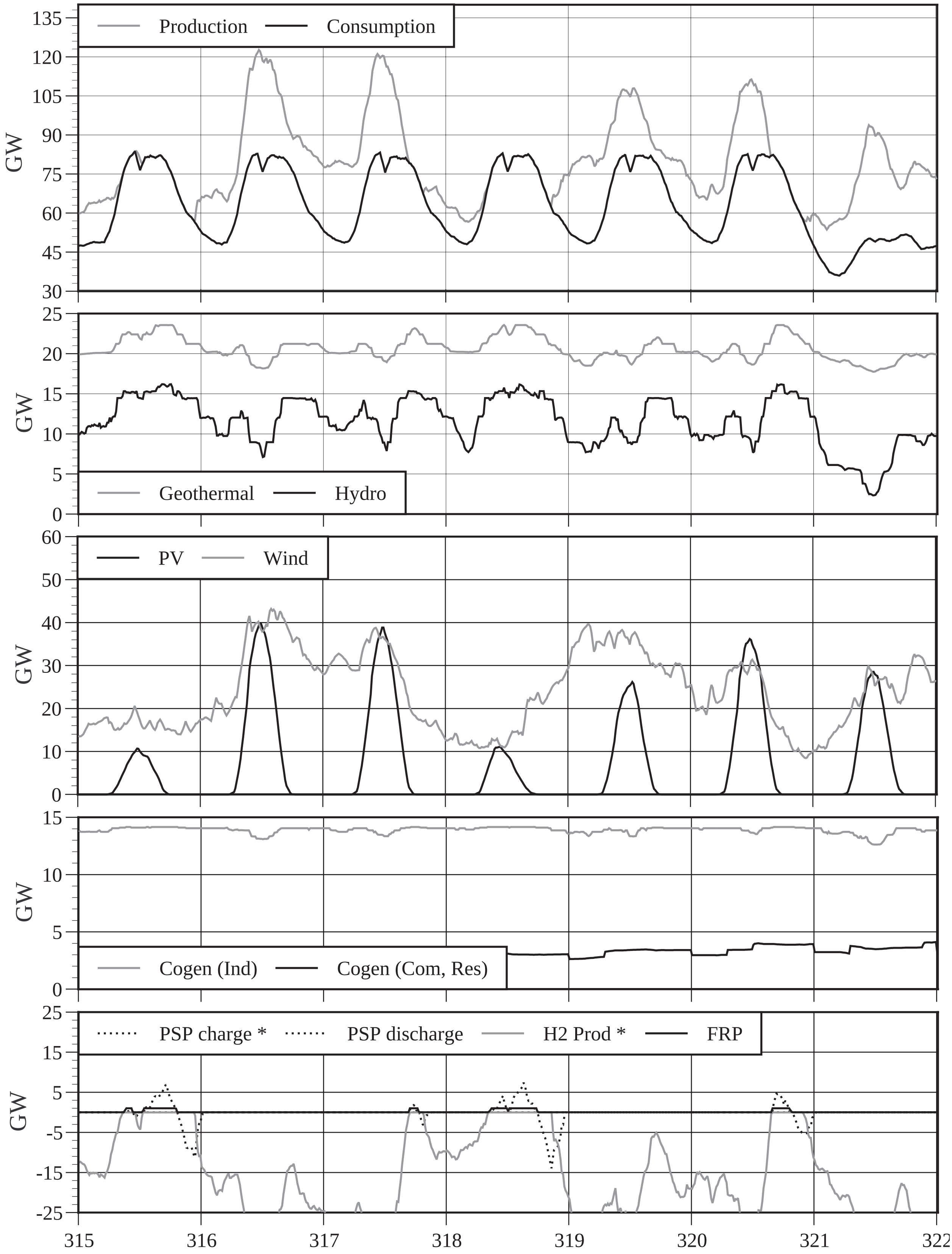


Figure 124 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 46. Source: ERJ.

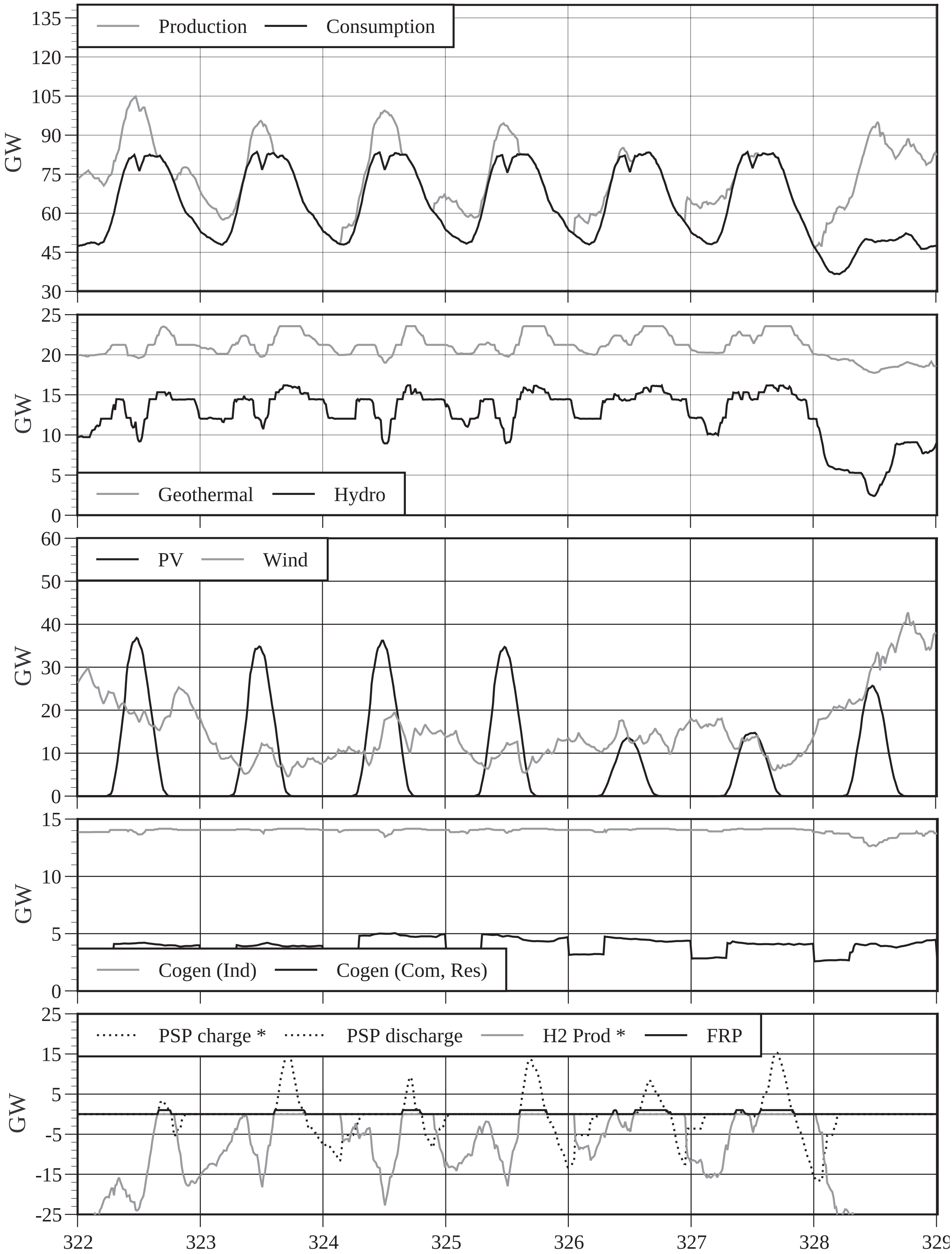


Figure 125 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 47. Source: ERJ.

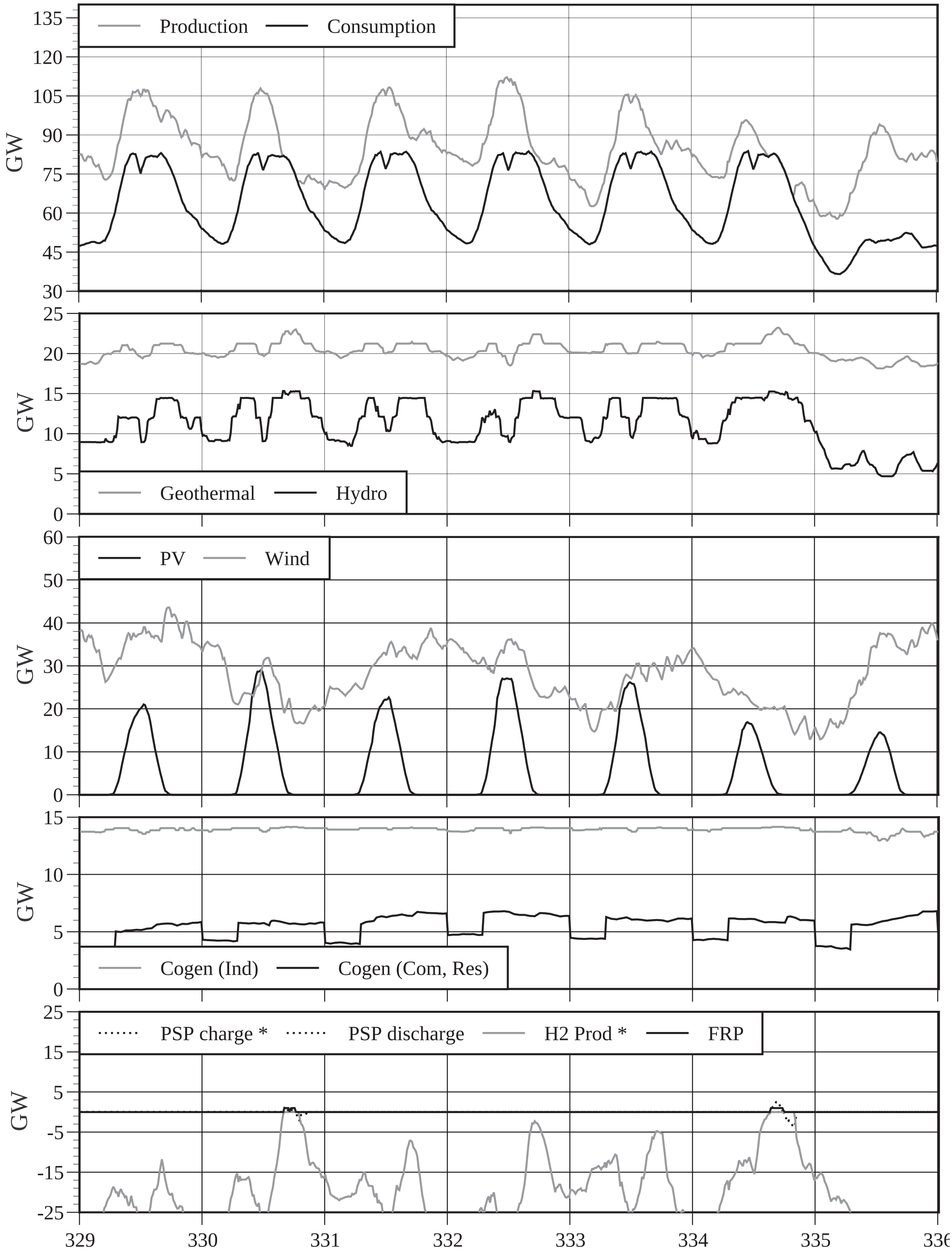


Figure 126 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 48. Source: ERJ.

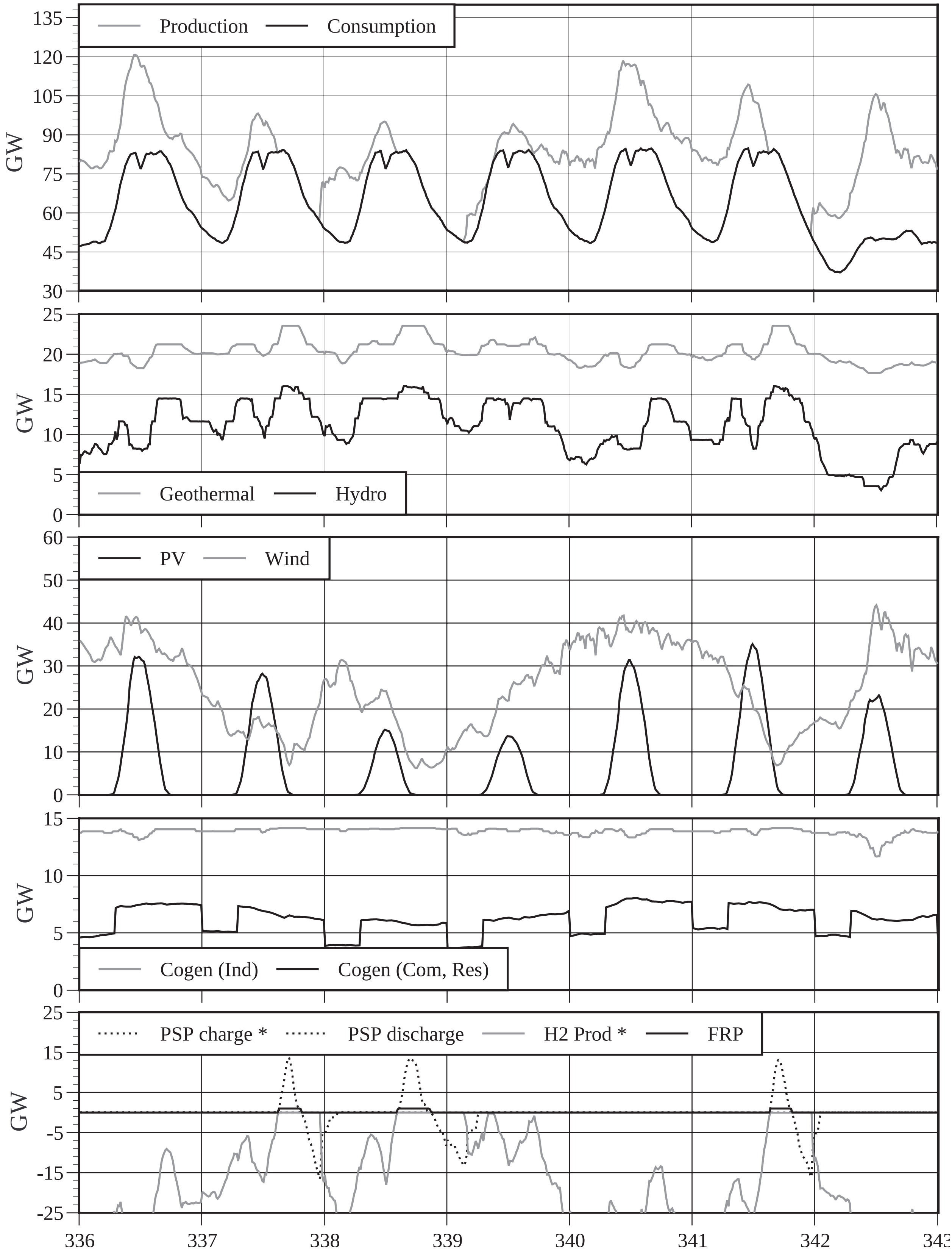


Figure 127 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 49. Source: ERJ.

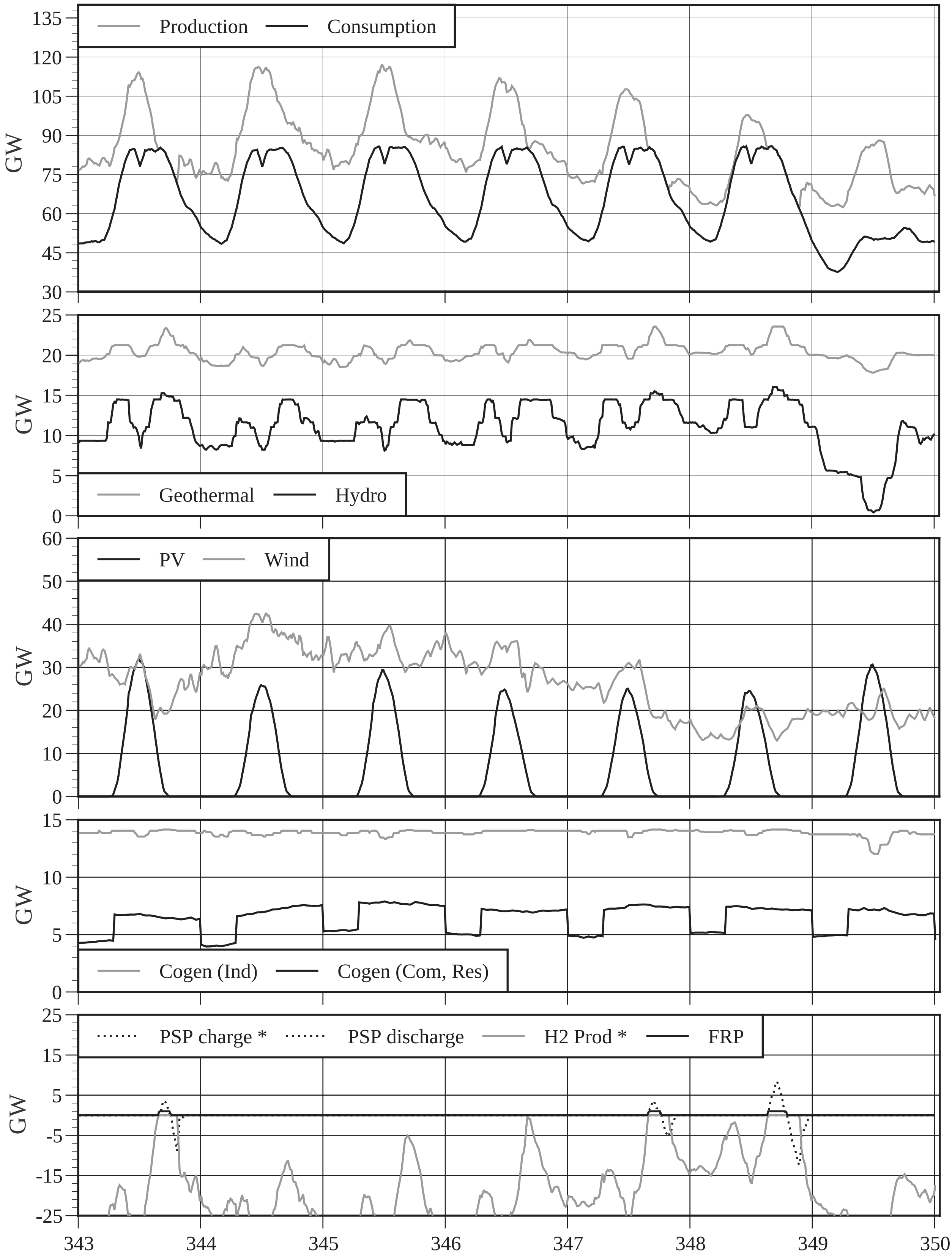


Figure 128 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 50. Source: ERJ.

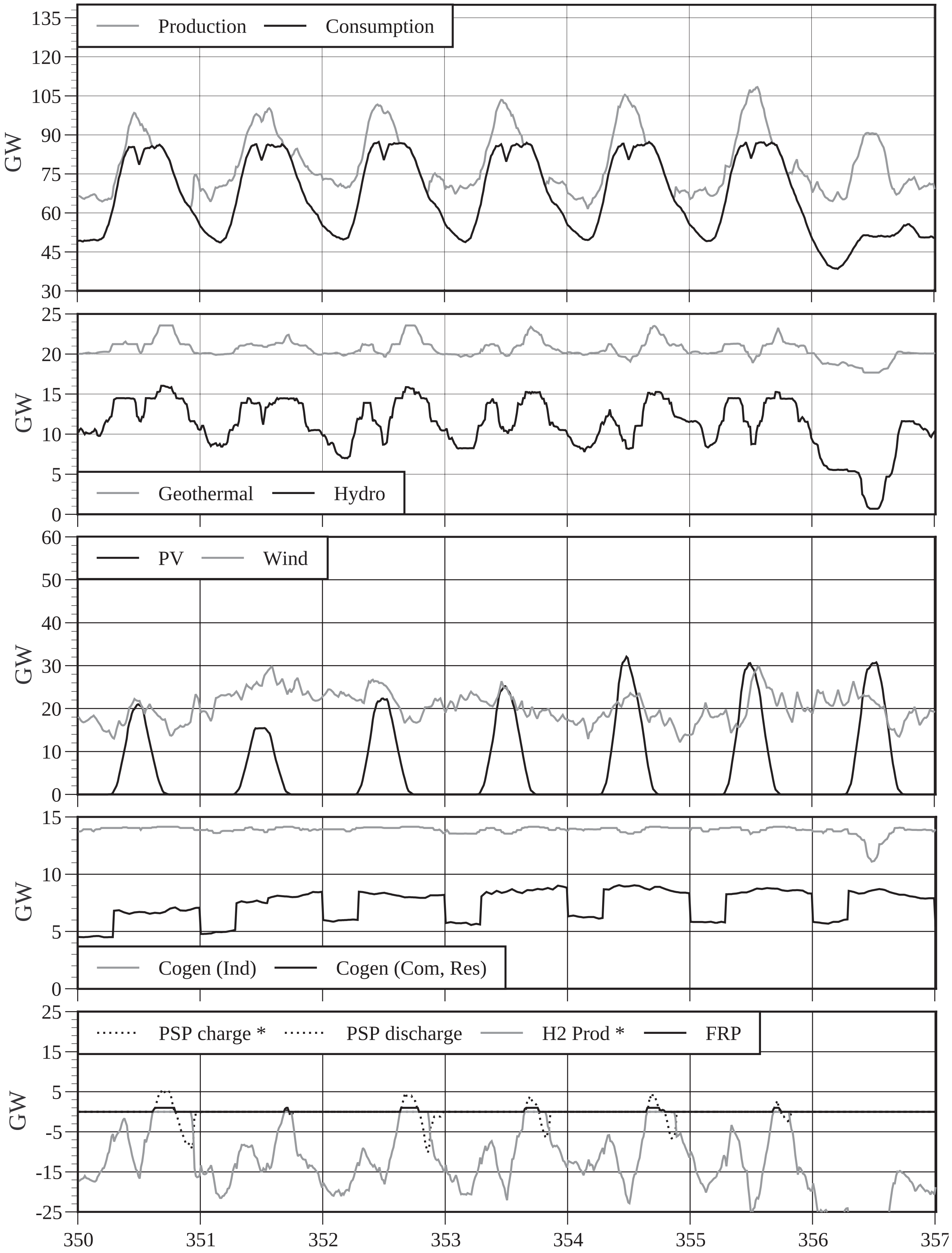


Figure 129 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 51. Source: ERJ.

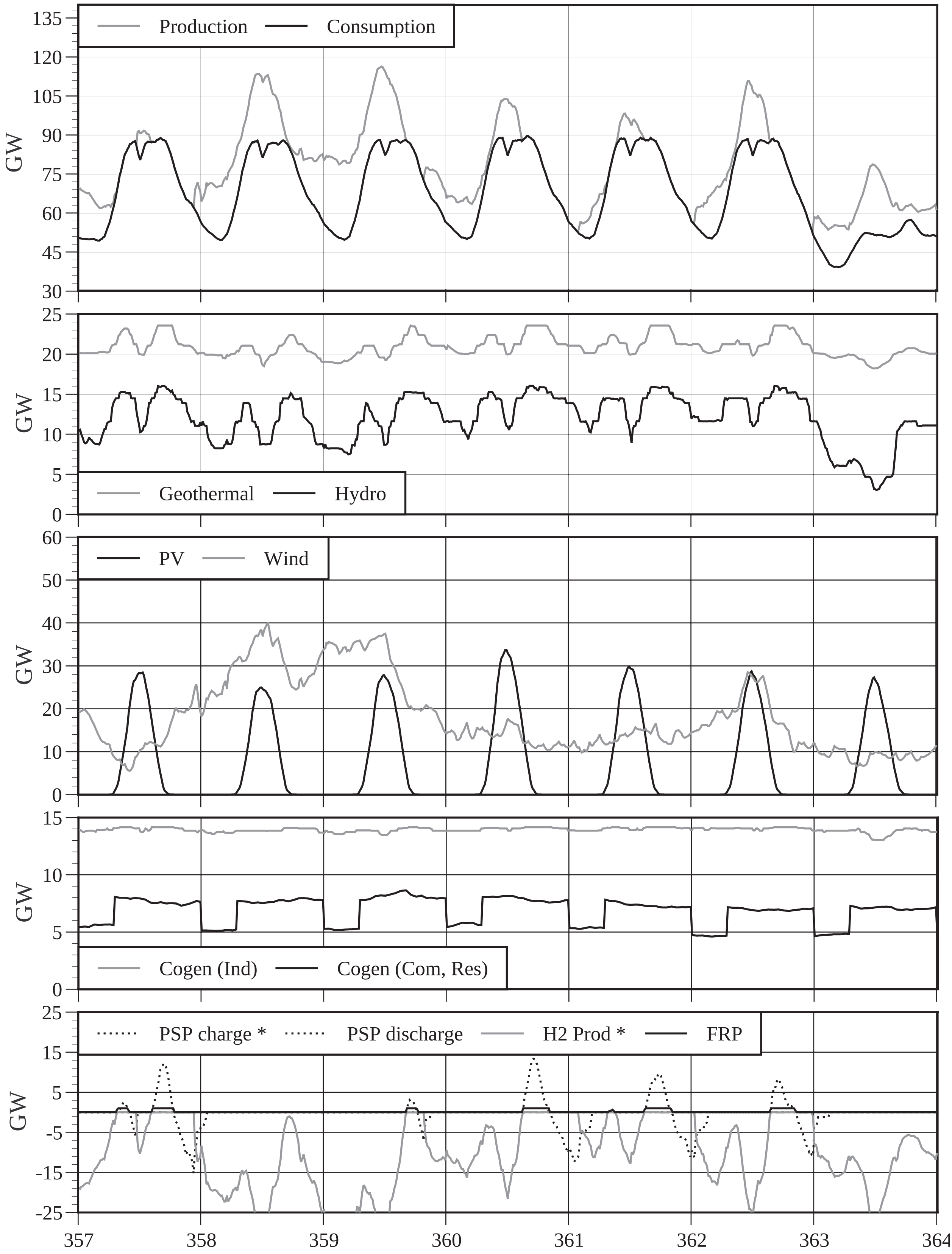
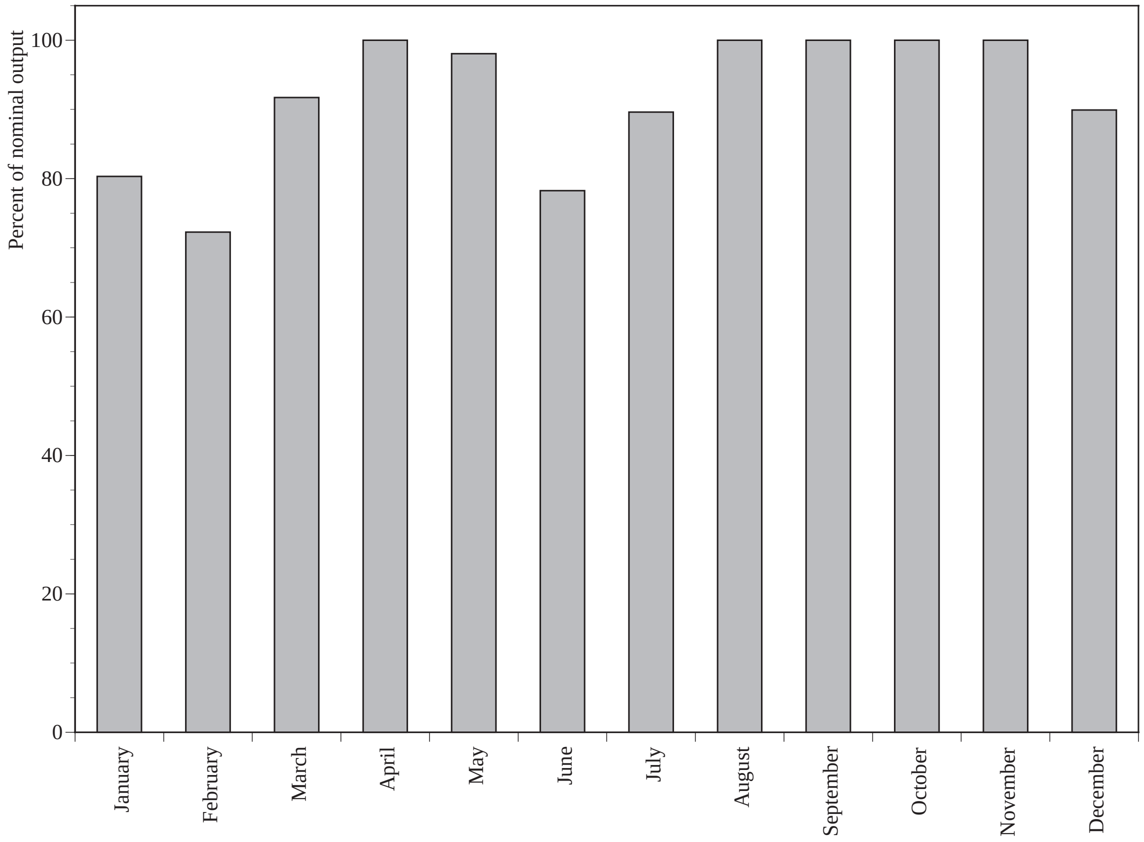


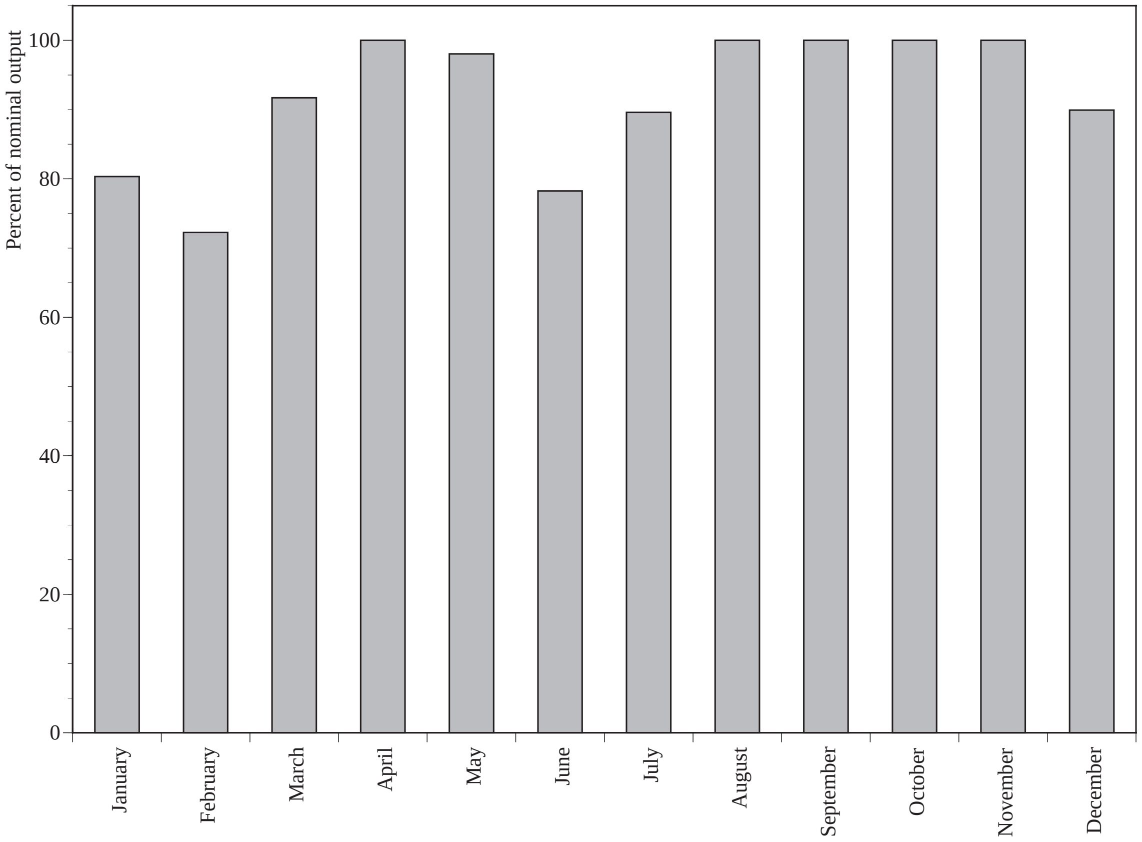
Figure 130 : The figure shows the energy supply by different technologies, the total demand and the storage of electrical surplus in hydrogen or pumped hydropower in Week 52. Source: ERJ.

13 Appendix - Nominal Monthly Hydropower Output



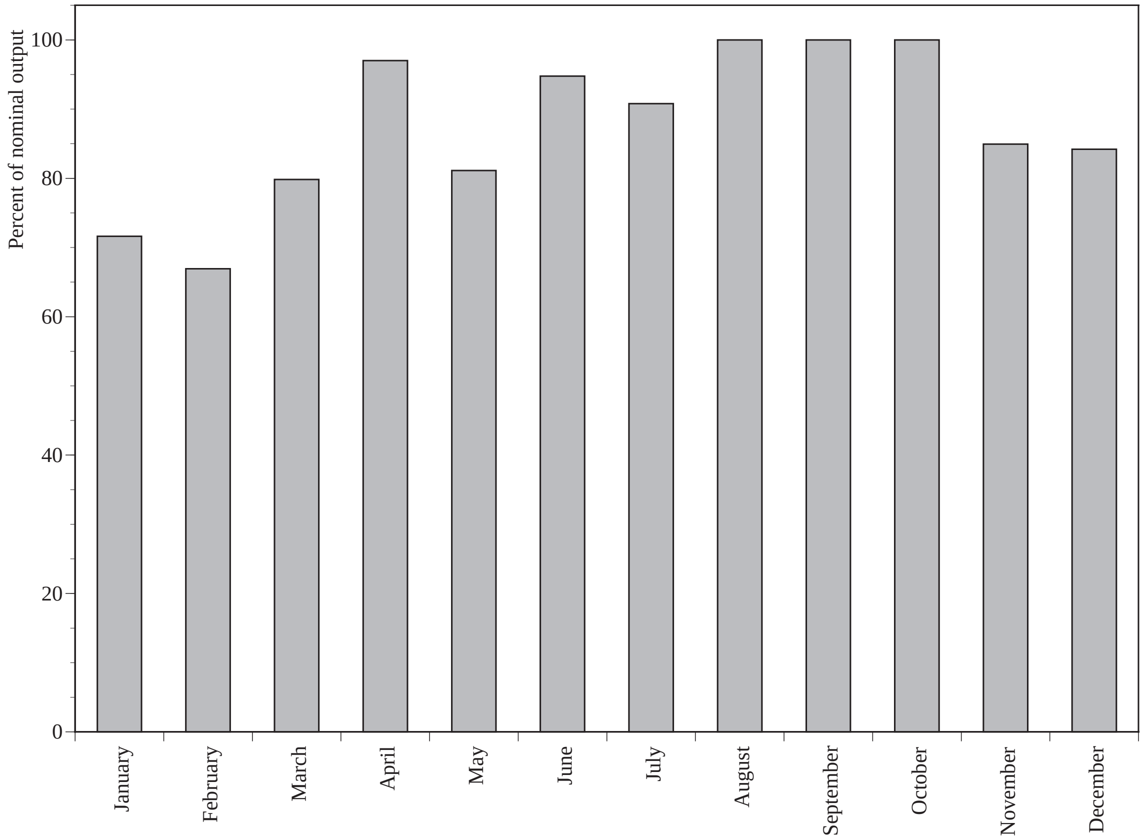
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 131 : Percentage of nominal output of Hydropower in Hokkaido East.



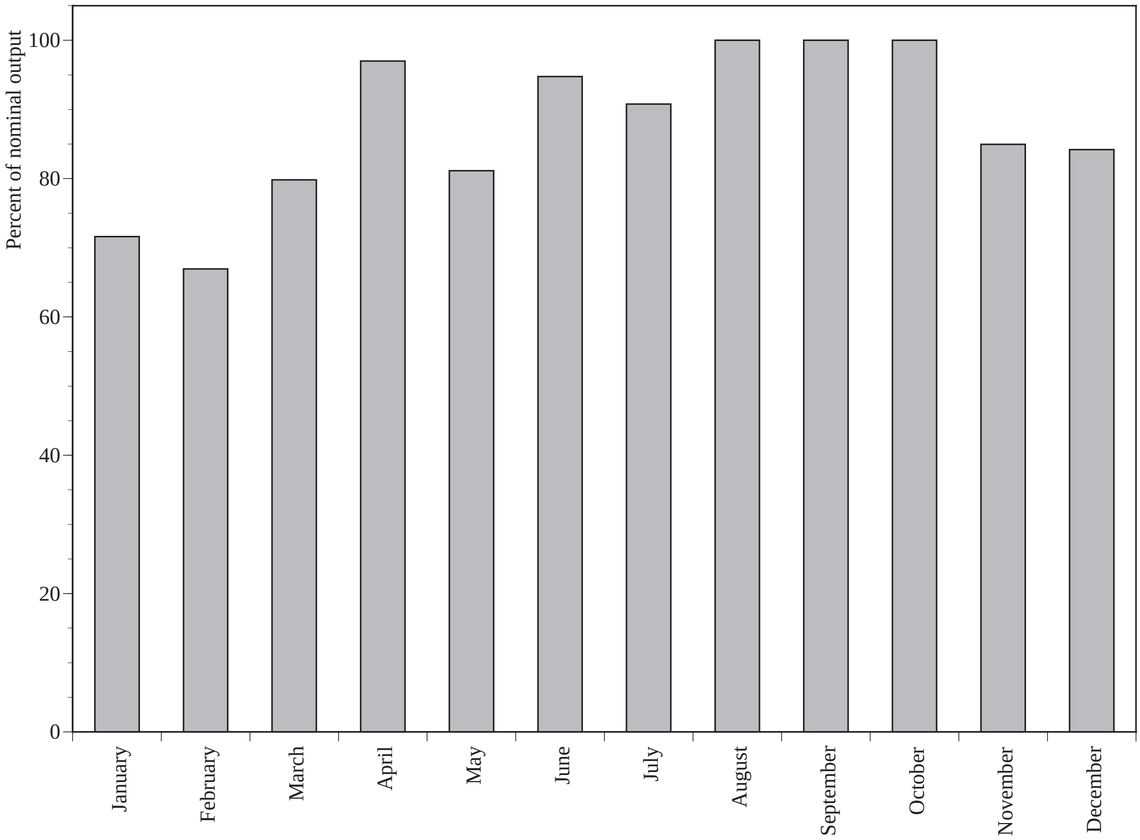
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 132 : Percentage of nominal output of Hydropower in Hokkaido West.



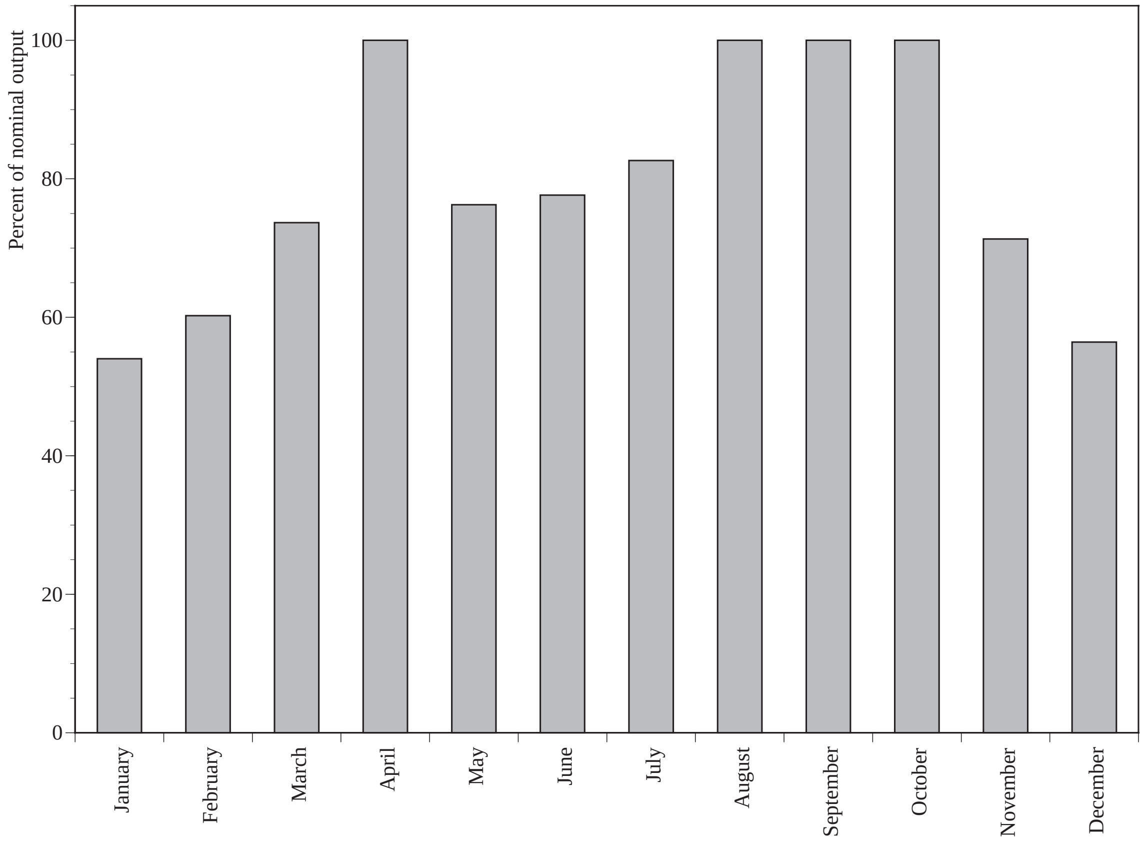
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 133 : Percentage of nominal output of Hydropower in Tohoku East.



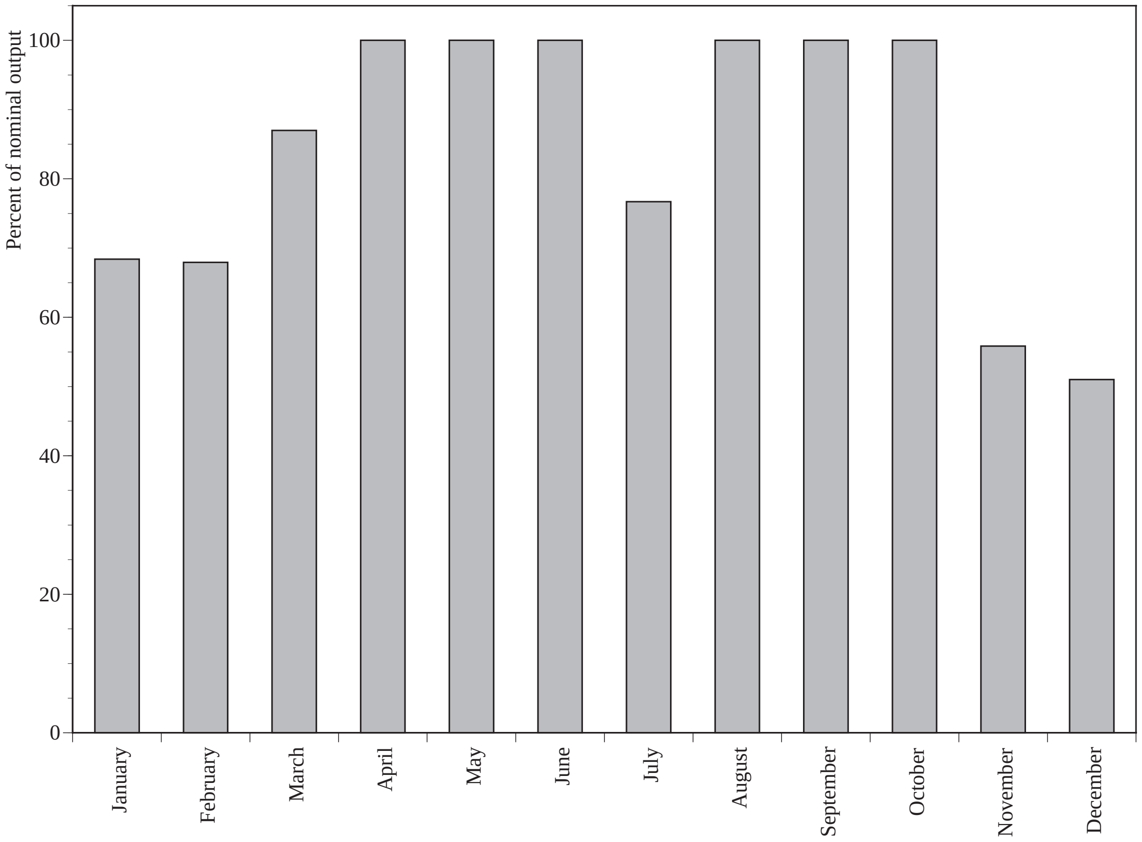
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 134 : Percentage of nominal output of Hydropower in Tohoku West.



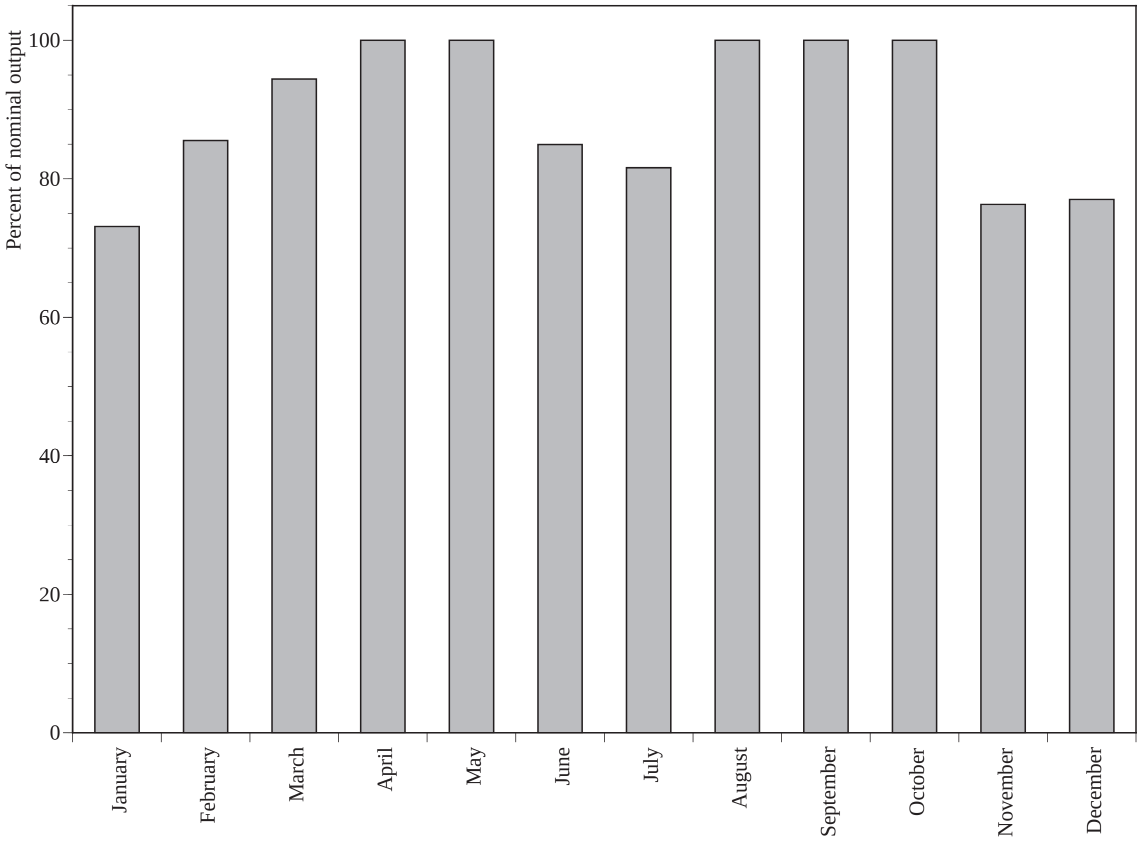
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 135 : Percentage of nominal output of Hydropower in Kanto.



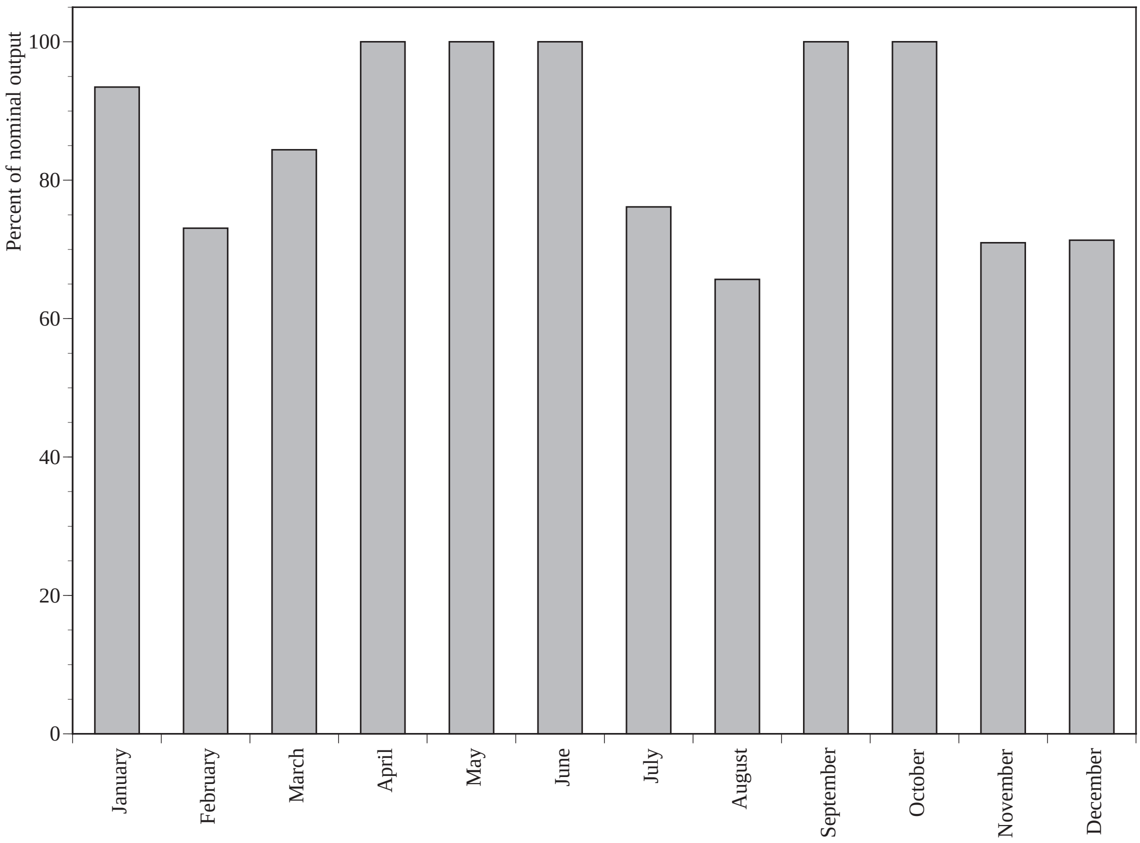
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 136 : Percentage of nominal output of Hydropower in Chubu.



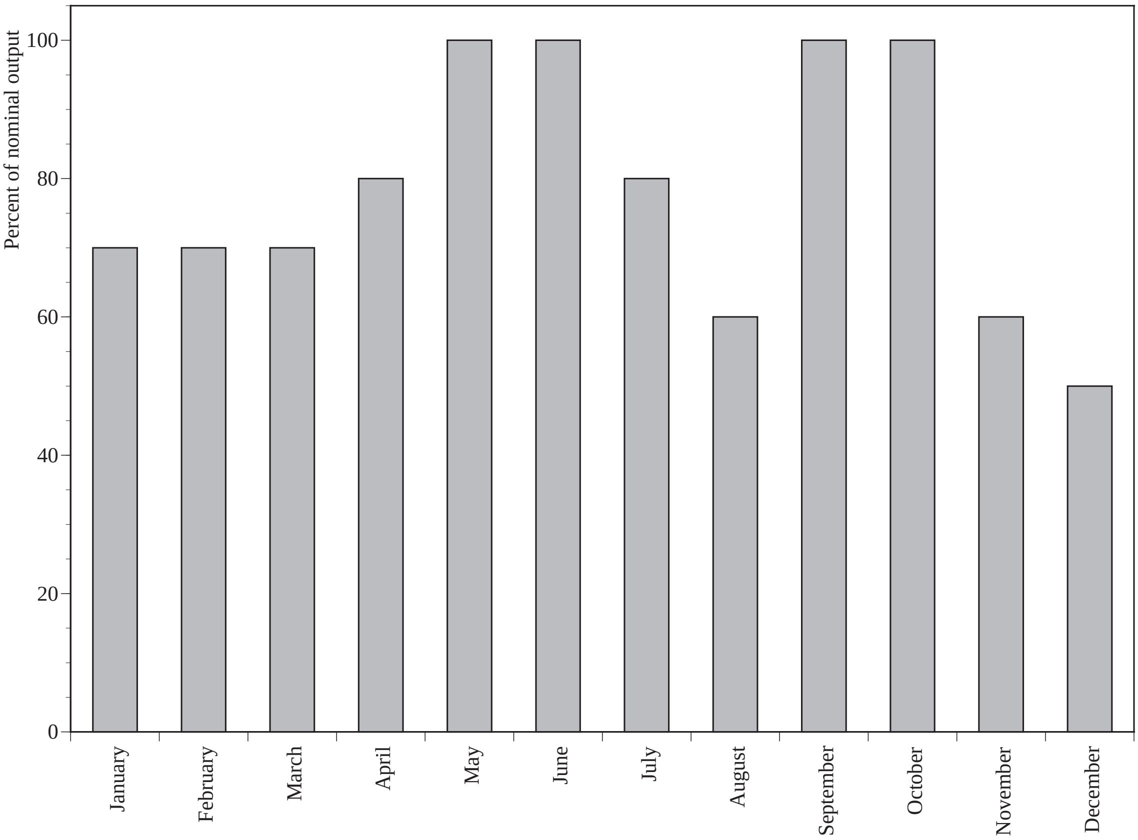
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 137 : Percentage of nominal output of Hydropower in Hokuriku.



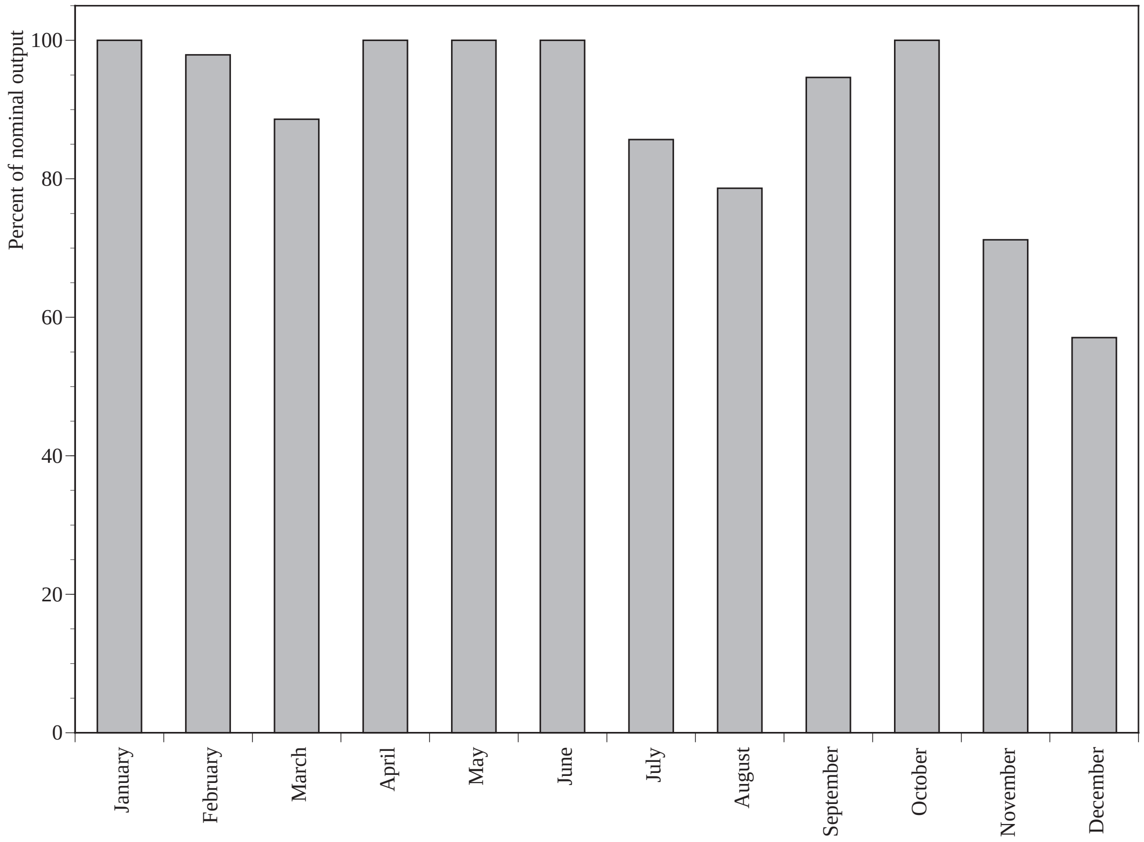
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 138 : Percentage of nominal output of Hydropower in Kansai.



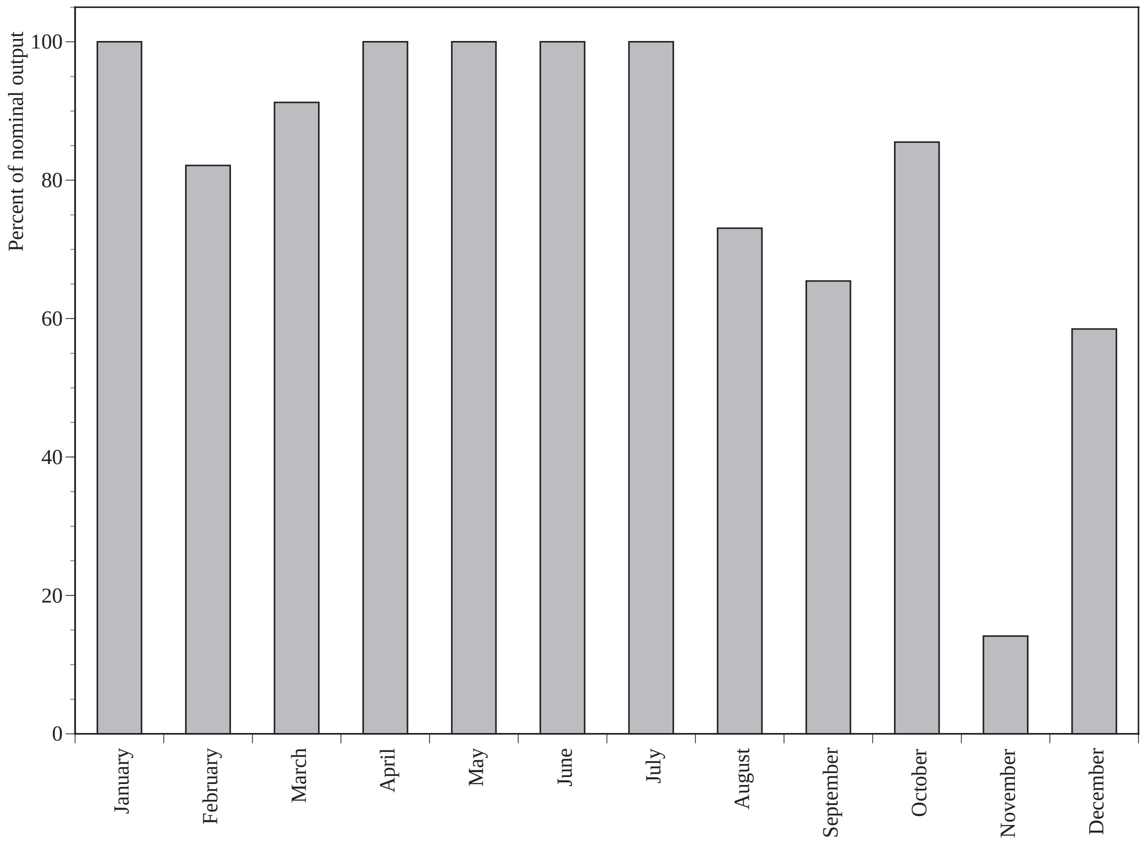
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 139 : Percentage of nominal output of Hydropower in Shikiku.



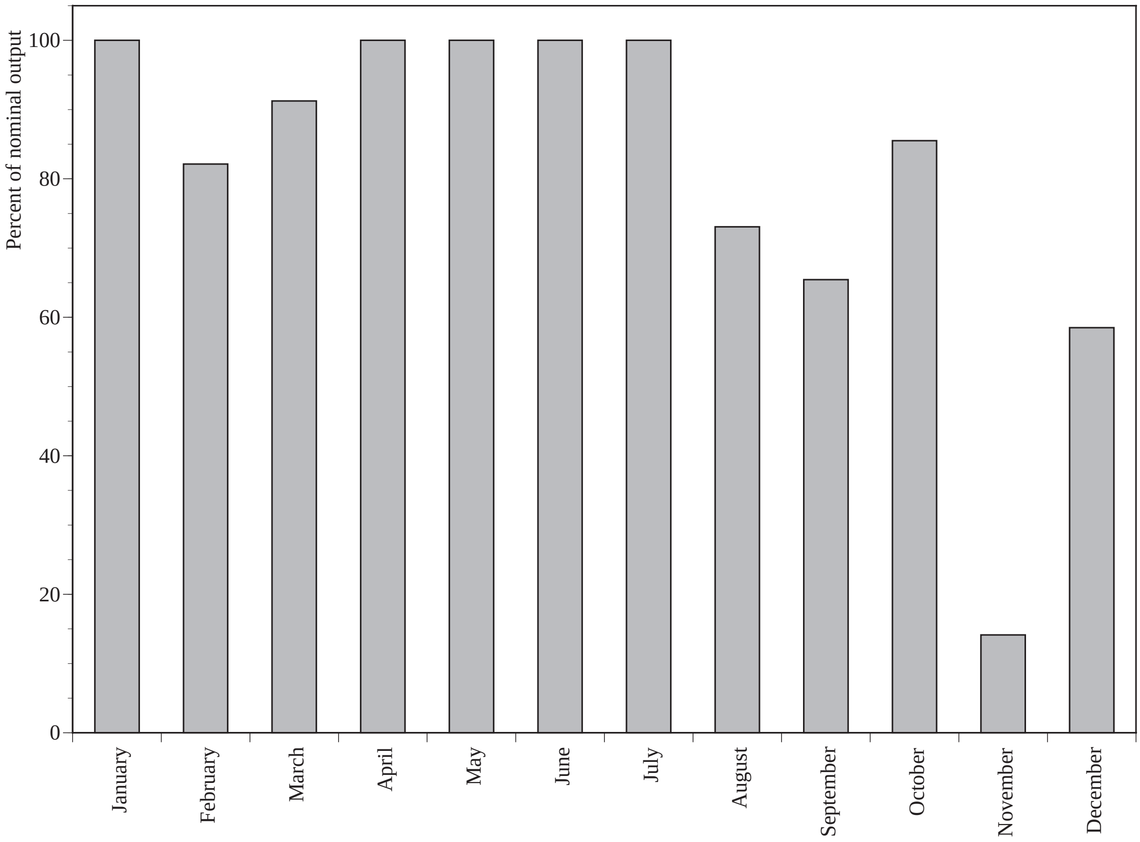
Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 140 : Percentage of nominal output of Hydropower in Chugoku.



Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 141 : Percentage of nominal output of Hydropower in Kyushu South.



Source: ERJ, Datasource : River Bureau Ministry of Land, Infrastructure and Transport.

Figure 142 : Percentage of nominal output of Hydropower in Kyushu North.

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