

Energy and Climate

Steering Committee Report

September 2023

מجلس التعليم العالي
המועצה להשכלה גבוהה
COUNCIL FOR HIGHER EDUCATION
הוועדה לתכנון ולתקצוב

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Preface - Prof. Yoseph A. Mekori, Chair of the Planning and Budgeting Committee of the Council for Higher Education

I am both thrilled and honored to write a few words at the opening of this report. Shortly after I entered office in December 2021, negotiations started concerning the new multi-year plan for Israeli Academia (2023-2028), including a flagship initiative in Sustainability and the Climate Crisis. The road was not an easy one, but once we received approval in principle, we began the process of formation, then nomination, of experts' steering committees in three areas chosen on the basis of existing strengths and growth potential: (1) Energy and Climate, (2) Agriculture, Food/Nutrition and Biodiversity, (3) Marine and Water Sciences.

The report you have in front of you is the result of six months of intensive work that included gathering input from key stakeholders in Academia and beyond, lively discussions, and a process of prioritization and cost/benefit analysis. It contains the recommendations of the Energy and Climate Steering Committee, most of which were endorsed by the Planning and Budgeting Committee. Thus, we are now in a position that we have the green light, and a guaranteed budget of nearly 187 million NIS, to put words into action in the coming five years.

This is a timely and most needed investment in research in avenues that were carefully chosen. We have solid grounds to believe that the Israeli scientific community has the potential to become a world leader in innovation and development in the field of sustainability, and are happy to be in a position that we can provide a financial boost. The world needs to act quickly in order to brave the daunting challenges ahead. We made sure that Israeli Academia will be able to contribute its share.

I would like to thank the chair and members of the three steering committees for their excellent work and contribution, completely pro bono. My thanks are also extended to the team at the Council for Higher Education, Naomi Beck (PhD), Deputy Director General for Strategy and International Affairs, Gabi Appel, Program Director for Strategy, and Yifaa Yungerman, Program Coordinator for Strategy, for their dedicated work.

The plan is laid, and now we must all endeavor to make it a success even beyond our expectations so that great science will have a great and lasting impact for the better.

Prof. Yossi A. Mekori
Chair, the Planning and Budgeting Committee
The Council for Higher Education

Mission Statement

The drastic global climate changes manifested in extreme weather patterns, rising global temperatures and increased CO_2 levels, are a net result of an exponential growth in usage of fossil fuels for more than a century to supply the world's energy demands. Hence, it is clear that sustainable energy research and climate change research are intimately connected. The devastating effects of climate change are all around us, and we, scientists, sense the responsibility to develop sustainable solutions to this global problem. While the origin of this problem is human-made, it is now escalating out of control in ways that only amplify it. For example, the melting of the polar ice caps and icebergs is changing the Earth's albedo, and the defreezing of the Russian Siberian tundra, is releasing immense amounts of methane (a more potent greenhouse gas than CO_2) into the atmosphere. Both phenomena will increase global warming. Therefore, it is imperative and urgent that as scientists we do everything in our capacity to find sustainable solutions to this immense problem.

The mission of the Energy and Climate Steering Committee was to recommend measures for strengthening the academic community in Israel in the fields Energy and Climate in order to encourage the most advanced, world-class research in these areas. There is an already well-established academic community in Israel in the field of energy, and to a lesser extent in the field of climate. Therefore, the Steering Committee recommended that further investment will focus on the creation of inter-university research centers where scientists will work collaboratively on carefully chosen, high-impact problems, including funding for infrastructure. In addition, the Committee also recommended supporting new faculty members and postdoctoral students via start-up grants and fellowships, correspondingly. Based on the track record of Israeli academia, I am confident that the funding secured by the Planning and Budgeting Committee of the Council for Higher Education towards sustainability related research, will position Israel at the forefront of the global race to find solutions to the climate change.

I would like to thank all the Committee members for their important contributions to this special committee. It was an honor and a pleasure to work together. Finally, I want to thank Naomi Beck and Gabi Appel for their close guidance and unwavering support during the whole process.

Prof. Gidi Grader
Technion-Israel Institute of Technology
Chair of the Energy and Climate Steering Committee

Abstract

Energy consumption per capita provides a reliable and direct measure of the development level of different countries. It was also found that the ratio between the GDP per capita of a given country and its energy consumption per capita is similar. It follows that countries with a low GDP aspire to increase the production and availability of energy (especially electricity) to their residents to enable development. This effect has led to an increasing use of fossil-fuel-based energy sources, such as coal and oil, that cause the global climate change we are witnessing today.

Given the growing need for energy in the modern world, it is imperative that we increase the share of renewable energy sources, and find ways to increase the efficiency of energy utilization, in an effort to stop global warming. The task of the Energy and Climate Steering Committee was to provide recommendations for research directions that would help establish the knowledge basis for tackling the global challenges, and enable the development of solutions to the climate problem. For this purpose, the Committee, comprising ten experts in the fields of energy and climate, discussed the various local and international challenges, and the opportunities for reducing research gaps and leveraging the strengths in Israeli Academia. The Committee's work led to a comprehensive program for the promotion of innovative and groundbreaking research in energy and climate fields.

The program proposed by the Committee includes recommendations for research centers, as described below, as well as start-up grants for new faculty members, and fellowships for postdoctoral researchers. With respect to the research centers: The Committee members recommended to focus, in the field of energy, on four, relatively wide, sub-fields, in which institutions would be given the flexibility to submit proposals that will be evaluated on the basis of scientific excellence. In the field of climate, the Committee members recommended supporting research centers in a more open, bottom-up approach, but provided examples of possible research projects. Finally, they also recommended supporting joint research centers for energy and climate interactions.

Research Centers – Energy (in four, broad, sub-fields):

1. Power Grids (sustainable microgrids, network management models, green building, urban planning, energy policy)
2. Alternative Fuels (sustainable hydrogen, fuel cell technologies)
3. Sustainable Solar Energy (solar fuels, PV, CPV and AgroPV)
4. Sustainable Batteries and Electrochemical Energy Storage

Research Centers – Climate (examples below):

1. The physical climate system
2. Extreme weather conditions and their effects
3. Biogeochemistry and the carbon cycle

Joint Research Centers - Energy and Climate Interactions

Background

Since the nineteenth century, and the industrial revolution, the world is facing a constant rise in the amount of greenhouse gases (GHG) emitted to the atmosphere, which lead to a phenomenon called global warming and to global climate changes that threaten humanity and the planet. The main reason for these changes is the uncontrolled rise in the usage of contaminating fossil fuels for transportation, industry and heating. Based on **The Annual Report of NOAA's Global Monitoring Lab** (Figure 1), in 2022, the global average atmospheric carbon dioxide concentration was 417.06 ppm (parts per million), setting a new world record. The increase between 2021 and 2022 was 2.13 ppm – and was the 11th year in a row during which the amount of carbon dioxide in the atmosphere increased by more than 2 ppm per annum.

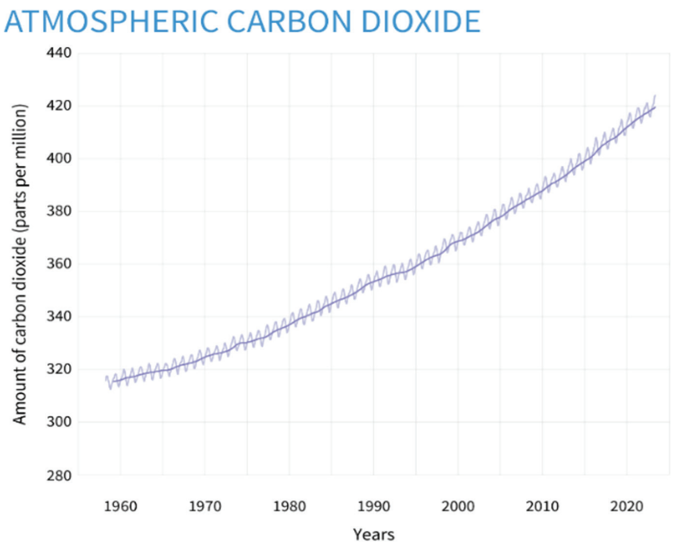

Figure 1. Global Annual Mean Carbon Dioxide Atmospheric Concentration (**source**)

Among several pollutants (Figure 2), carbon dioxide (CO_2) and Methane (CH4) are the most important greenhouse gases in the atmosphere, and together they are responsible for more than 90% percent of the effect above (see **here**). These gases absorb and radiate heat, thereby reducing the emission of heat from Earth to outer space and leading to a further increase in global temperature.

According to **the Sixth Assessment Report of the UN Intergovernmental Panel on Climate Change** (IPCC), more than 40% of the world's population live in places and situations that are "highly vulnerable to climate change," and are According to the Sixth Assessment Report of the UN Intergovernmental Panel on Climate Change (IPCC), more than 40% of the world's population live in places and situations that are "highly vulnerable to climate change," and are already experiencing the effects of climate change. For example, currently, maximum temperatures reach 50° degrees Celsius across Europe, and wildfires are spreading rapidly due to the extremely hot environment. We have witnessed similar effects recently in the wildfires in the eastern part of Canada and in the western part of the USA. If global average temperatures continue to rise by more than 1.5 degrees Celsius, some environmental changes could become irreversible.

Most of the world's primary energy (~95%) comes from fuels, most of which are fossil fuels. This means that most of the world's energy supply emits carbon dioxide when it undergoes combustion in order to produce energy. Therefore, some of the world's leading countries have set out goals to reduce carbon dioxide emissions significantly by 2050. Additionally, different scenarios of energy utilization of different sources can predict the ultimate estimated global consumption, as depicted in Figure 3 below. It follows that in order to minimize greenhouse gas emissions, and mitigate global climate change, there is an urgent need to use clean, renewable and carbon-free sources of fuels. In addition to global environmental concerns, interest in renewable energy sources has gained attention due to local and geo-political stresses, such as the Russian-Ukrainian war, which caused an energy crisis in Europe, demonstrating the importance of developing an energy security plan, a need that also applies to Israel.

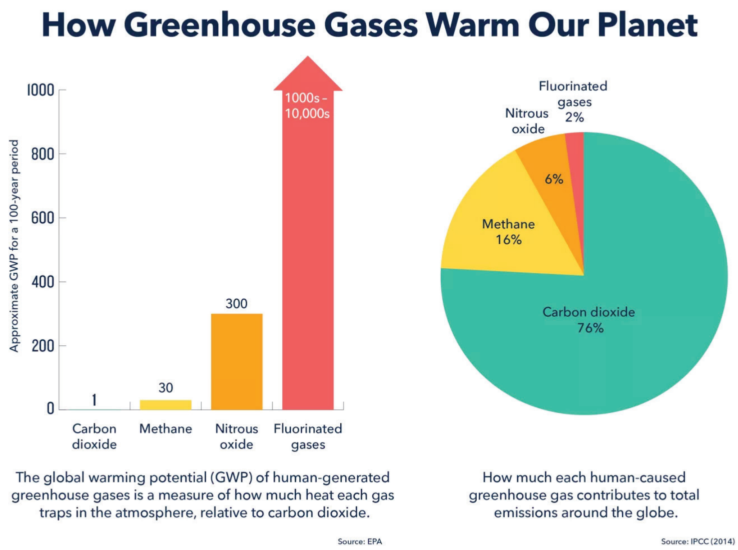

Figure 2. The Effect of Greenhouse Gas Emissions on Global Warming (source)

Israel is located within the global solar belt, with demonstrated capacity for developing technologies to utilize solar energy for conversion and storage of energy. Examples of this include production of photovoltaic energy, thermo-solar technologies, technologies for the storage of electricity in batteries, and the production of green hydrogen. Several start-up companies were established in these fields in Israel over the past few years and many are still active. For instance, hydrogen energy is widely considered the most cutting-edge because it offers the highest energy mass density, and a clean combustion product (water) in comparison to other energy carriers such

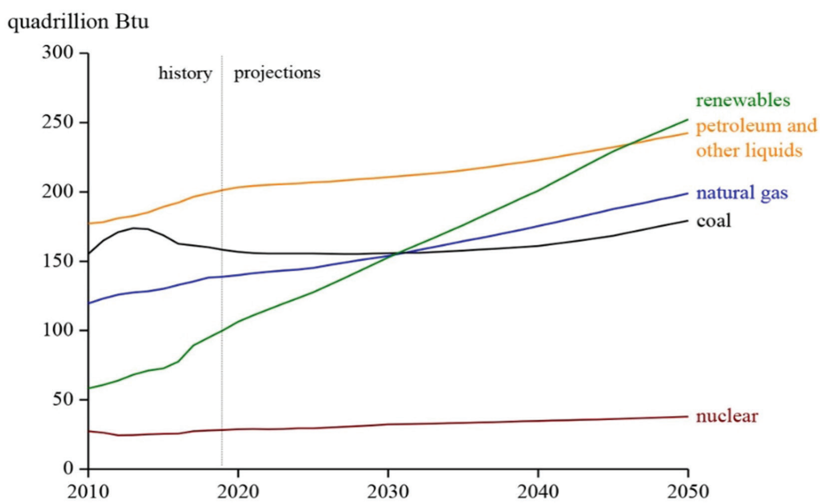

Figure 3. World primary Energy Consumption by Energy Source (Source)

as hydrocarbons. In addition, once cheap hydrogen will be available on a large scale, capturing CO_2, and developing hydrogenation technologies to convert it into useful products, will offer additional pathways to prevent uncontrolled CO_2 emissions and the release of greenhouse gases into the atmosphere.

Beyond the development of clean and efficient technologies for the production, storage and conversion of energy, we must also develop better utilization pathways such as buildings and electrical grid systems that are more energy efficient. The large-scale usage of clean energy requires further interdisciplinary scientific development to facilitate Israel's commitment to reduce emissions through the use of renewable energy sources. In parallel, it is highly important to arrive at a better understanding of the diffusion of pollutants in the atmosphere, and develop models for the prediction of climate patterns on a local scale. Such understanding can help to predict the occurrence of storms and extreme weather conditions, thus providing early warning to the population. The aim of the 5-year plan described below is to provide support for the advancement of a select number of academic research centers in the fields of sustainable energy and climate.

Composition and Mode of Work of the Steering Committee

The Steering Committee was assembled starting with the appointment of the Head of the committee, Prof. Gidi Grader, who has expertise in the field of energy. Then, following consultation with Naomi Beck (PhD), Deputy Director General for Strategy and International Affairs at the Council for Higher Education, several scientists were approached, aiming for a balance of expertise in the different disciplines under the Committees' responsibility, and considering gender balance and representation of the different academic institutions in Israel. A representative of the Council for Higher Education, Prof. Yossi Rosenwaks was also nominated to the Committee. The selection of Committee members was also done while avoiding potential conflicts of interest. Below is a table of the Committee's composition, divided into two sub-panels according to expertise (+) in Energy and Climate research.

Composition of the Energy and Climate Steering Committee

Members (and affiliation)	Energy	Climate
Prof. Gideon Grader (Technion- Israel Institute of Technology) - Chair	+	
Prof. Lior Elbaz (Bar-Ilan University)	+	
Prof. Itai Halevi (Weizmann Institute)		+
Prof. Nili Harnik (Tel Aviv University)		+
Prof. Iris Visoli Fischer (Ben-Gurion University)	+	
Prof. Meital Kasperi Toroker (Technion)	+	
Prof. Efrat Morin (Hebrew University)		+
Prof. Yoad Zur (Technion- Israel Institute of Technology)	+	
Prof. Yossi Rosenwaks, Member of the Council for Higher Education (Tel Aviv University)	+	
Prof. Danny Rosenfeld (Hebrew University)		+

The Committee convened a number of times from January-May 2023 in different formats: face-to-face meetings on January 1st, March 19th, and April 16th, followed by a fourth, online meeting on May 29th. A sub-committee on climate met separately a few times online: on April 3rd, April 19th, April 27th and May 1st.

During the first meeting, the Committee members introduced themselves and were asked to suggest topics that they deem crucial for the advancement of energy and climate research. Members talked about what they consider to be bottlenecks that need to be addressed, such as: carbon dioxide conversion processes, hydrogen technologies, hydrogen energy utilization, energy storage, the establishment of a geophysics center, the establishment of carbon capture centers, use of technologies for converting biomass into fuels, and the development of materials that will be used in various technologies to reduce air pollution and climate risks. They further indicated the need to address the interface between the Committee's sub-fields, i.e. the interactions between energy and climate.

The Committee's Chair proposed to put together a list of ideas that would later be validated vis-à-vis the needs and desires of the universities. To map the latter, the Chair proposed adopting a survey drafted by the Chair of the Agriculture, Food/Nutrition and Biodiversity Steering Committee. The survey was forwarded to the Committee members for their comments, and a final, modified version was sent to the presidents of the public universities (including the Open University).

The Survey

The survey consisted of 10 questions for each sub-field:

Questions 1 to 6 aimed at understanding the Institutions' needs and competencies

1. List up to 5 topics in each category, that you define as foci of excellence in your institution in sustainability research.
2. List names of up to 10 scientists from your institution, in each category, who are experts in these fields (you may include both established and young PIs).
   Please provide separately the top 10 recent publications for each scientist (incl. links to articles when possible).
3. List 2 Infrastructures you consider necessary to promote excellence in sustainability research in your institution in each category.
4. List up to 3 tools (other than infrastructure) you think would enable to promote excellence in sustainability research, e.g., Research Grants, Hiring new PIs, Fellowships, Teaching, Other.
5. Name 2 centers of excellence that you wish to establish in your institution in each topic.
6. Other comments/suggestions

Questions 7 to 10 aimed at getting experts' feedback.

7. What are the greatest sustainability-related challenges that we are likely to face in the coming decades in each category?
8. What are the greatest foreseeable opportunities for advances in sustainability science in each category?
9. What fundamental knowledge gaps exist that limit the ability of scientists to respond to these challenges as well as take advantage of the opportunities?
10. What general areas of research should be advanced and supported to fill these knowledge gaps?

The results of questions 1-6 of the survey in the sub-field of energy were reorganized according to the number of times a certain topic/answer repeated itself, as shown in Table 1 below (the results of questions 7-10 were not ranked in the same manner).

In parallel, the members of the climate sub-committee decided to provide their own answers to the survey (see Table 2 below), and compare them with the answers received from the universities, before making their recommendations.

1. List of acronyms used in the tables: IIT - Israel Institute of Technology (Technion); BIU - Bar-Ilan University; WIS - Weizmann Institute of Science; BGU - Ben-Gurion University; HUJ - Hebrew University of Jerusalem; TAU - Tel-Aviv University; Haifa - Haifa University; Ariel – Ariel University; OU – the Open University.

Table 1 – Energy

Survey Answers to Questions 1 and 3

Question 1: Foci of Excellence	
Hydrogen, fuel cell technologies	Ariel, BIU, BGU, IIT, HUJ, TAU, WIS, OU
Alternative fuels, biofuels/waste	Ariel, BIU, BGU, IIT, HUJ, TAU, WIS, OU
Batteries & electrochemical energy storage	Ariel, BIU, IIT, HUJ, TAU, WIS, OU
Solar Energy: PV, CPV, AgroPV, Solar Optics	BIU, BGU, IIT, HUJ, TAU, WIS
Integration and grid management	BGU, TAU, IIT, BIU
Energy Policy and management models	BGU, HU, TAU
Green building and sustainable urban planning	BGU, HUJ
Catalysis & nanomaterials and computational materials	Ariel, BIU, BGU, IIT, WIS, OU
Energy from waves & wind	BGU, HU, IIT, HUJ, WIS, OU
Seismic hazard during subsurface fluid injection - Part of climate	HUJ, HU
Sensors	BIU
Solar Optics	BGU

Question 3: Infrastructure Needed	
Infrastructure for material development and characterization: including film deposition, SIMS, AFM, reactors, and catalysis	Ariel, BGU, IIT, HUJ, WIS, OU, BIU, HU
Infrastructure for hydrogen generation and characterization	BIU, BGU, IIT
Battery testing lab	BIU, IIT
:Infrastructure for Electric grid simulation	TAU
Computing facilities	HU, WIS
Laboratory for advanced multidisciplinary research	Ariel

Table 1 – Energy (Cont.)

Survey Answers to Questions 4 and 5

Question 4: Tools for Promoting Research (other than infrastructure)	
Research grants Individual or collaborative at the national level	Aiel, BIU, BGU, IIT, HUJ, TAU, WIS, OU
Support for hiring expert staff scientists (PhD level)	Aiel, BGU, IIT, TAU, WIS
Fellowships to attract students/postdocs in energy	Haifa, Kinneret, Tel-Hai, TAU, WIS, HUJ
Postdocs going abroad in energy	BIU, HU, IIT, WIS
Promoting the hiring of new PIs	BIU, BGU, HUJ, TAU
International and national collaborations: support international collaborative research, travel of students/postdocs	HUJ, TAU, WIS
Teaching programs and courses	Ariel, TAU
Data bases including energy reports	HU

Question 5: Centers of Excellence	
Center for green hydrogen production and utilization:	BIU, IIT, BGU
Energy storage devices	Ariel, BIU, WIS
Energy systems center	Ariel, HUJ
Center for Renewable heat technologies	BGU
Center national electric grid Center	TAU
Center for Sustainable Process and Catalysis	IIT
Power electronics and energy labs	TAU

Table 2 - Climate

Response of the Sub-Committee Members to Questions 1, 3, 4 and 6

Question 1: Foci of Excellence
Impact of clouds and aerosols on climate and energy budget
Mediterranean weather, climate, and hydrology
Ocean-atmosphere climate dynamics
Satellite atmospheric observations
Global carbon cycle
Paleoclimate
Maybe for other committees
Agricultural climate impacts

Question 3: Infrastructure Needs
Computer and technical support for cloud and climate simulations
Long-term, high-quality research personnel for model and dataset development, maintenance, and analysis
Long-term commitment for national data center
National analytical facilities for climate/environmental studies (e.g., mass spectrometry, chemical analysis, aerosol measurements)
Weather surveillance radar with dedicated personnel (maintenance, data analysis)

Question 4: Tools for Promoting Research (other than infrastructure)
Funding for high level technical personnel
National level educational programs (courses, summer schools, etc.)
Fellowships for Israeli postdocs to be involved abroad in state-of-the-art research
Regular competitive scholarships for graduate students
Dedicated funds for collaboration with the Meteorological Service (improve fundamental understanding and Meteorological Service)
Active Israeli involvement in relevant international organizations (e.g., ECMWF, EUMETSAT, ICDP, HORIZON)

Question 6: Other suggestions
Bottom-up definition of research avenues breaking disciplinary silos?
Invitees(?): land surface-atmosphere interactions (Dan Yakir), Nir Stav & Yoav Levy (IMS), sea level (Moti Stein, Laure Zanna) and cryosphere, paleoclimate (Yoni Goldsmith, Yehuda Enzel), מינהל התכנון.
Fellowships for Israeli postdocs to be involved abroad in state-of-the-art research

Table 2 – Climate (Cont.)

Response of the Sub-Committee Members to Questions 7-9

Question 7: The greatest sustainability-related challenges in the coming decades
• Understanding and quantifying climate sensitivity (inc. aerosols, cryosphere, sea level rise, tipping points, etc.), on global to local scales. • Understanding and quantifying probability distributions of meteorological and relevant environmental parameters, on global to local scales, with an emphasis on extremes. • Climate stabilization (inc. atmospheric CO_2, geoengineering). • Reducing uncertainty in climate and weather predictions and improving model-observation agreement (e.g., by improving model parameterizations, data assimilation). • Bridging the gap between basic research, practical implications, and climate risk (inc. effective communication of research findings and academic-industry-government relations, stakeholder interface). • Reducing uncertainty in projected sea level rise and associated impacts.

Question 8: The greatest foreseeable opportunities for advances
• New capabilities for improvement of observations (satellites, drones, robotic exploration, radars, innovative sensing technology, citizen science). • Emerging computer power and methodologies (inc. AI, high-level and novel statistics, inverse modeling and data assimilation). • Inter/multi-disciplinarily (e.g., Earth-systems approaches, natural-social science interactions, academic-policy interactions), inter-institutional and international collaboration.

Question 9: Fundamental knowledge and technological gaps that limit the ability of scientists to respond to these challenges/take advantage of the opportunities?
• Hydrometeorology • Cloud physics • Regional-scale land surface-atmosphere interactions • Downscaling and regional models of coupled ocean-atmosphere-biosphere • Strategies and impacts of scalable carbon management and geoengineering • Paleoclimate and paleo-sea level reconstructions relevant to climate predictions (inc. inverse models) • Reducing climate uncertainty (e.g., emergent constraints, paleoclimate) • Improving parameterizations

Important topics currently insufficiently covered in Israel According to the Climate Sub-Committee
Meso-scale meteorology
Urban meteorology
Climate model development
Regional climate and weather predictions, downscaling
Now-casting and weather hazards
Paleoclimate measurement incorporation into climate predictions
Land-atmosphere interactions, evaporation, evapotranspiration, including their model representation

Recommendations of the Steering Committee

The Steering Committee recommended supporting research centers in the fields of energy, of climate and also the interactions between energy and climate research, along with recommendations to establish start-up grants for new faculty members (infrastructure and research), and a fellowship program for postdoctoral researchers. With respect to the research centers in energy, two alternatives were raised in the committee's discussions: one that the Committee will decide top-down, from a macro perspective, on specific areas of focus for the research centers, and the second was to provide only a list of examples thus allowing greater flexibility in formulating bottom-up proposals for research centers. Finally, it was decided to recommend that support for the energy research centers will be limited to four relatively broad sub-fields that are solidly anchored in basic science and present potential for applied research. Universities will be given the flexibility to submit whichever proposals they choose within these four sub-fields, and these proposals will be ranked according to scientific excellence. Thus, it is possible that support will be given more than one research center in a given sub-field, even at the expense of including a different sub-field. In addition, the members of the energy sub-committee recommended that the research centers will be formed via collaboration of scientists from at least two different universities, and will be required to address the methodology of LCA (Life Cycle Analysis), as well as the economic implications of the proposed research project.

With respect to the climate research centers, an initial proposal was made to define thirty topics of research, out of which centers in the various sub-fields would be composed. After discussions, the list was reduced to seven topics, and finally it was decided that there would be no top-down limitation, only a mention of potential topics, which would serve as examples, allowing more flexibility for bottom-up proposals.

In addition, the Committee decided to recommend providing support for joint research centers on the interactions between energy and climate, and also recommended that all research centers be composed of groups of researchers from at least two different universities.

Below are details about the research centers recommended by the Committee.

Energy Research Centers

(100M NIS to support 4-8 research centers, maximum 25M NIS per proposal)

1. **Power Grids (Sustainable Microgrids, Network Management Models, Urban Planning, Energy Policy)**
   The way we power our homes, cities, and cars is rapidly changing to include more green and renewable technologies such as hydrogen fuel cells, electric cars, and solar panels. The incorporation of these systems into a national electrical grid on a large scale presents fundamental challenges in grid stability and management, which requires a complete overhaul of the grid. The Israeli grid is not prepared for these vast changes and new control and management

algorithms are essential for a safe and stable operation of the grid in the near future. In Israel, research of this type is made even more difficult since access to the grid data for research purposes is restricted and treated as classified for security purposes.

To achieve reliability and stability, deployment of large-scale energy storage systems and complex new communication and control algorithms are required. To lead this transformation, there is a need for a well-endowed research facility where reduced-scale models of the electric grid can be studied experimentally under real operating conditions accounting for renewable sources, various energy storage technologies, and the use of electric transportation. This need is even stronger given that the Israeli grid is relatively small and isolated. This makes our grid possibly more exposed to the risks of instability (oscillations or blackout) due to the intermittent nature of renewable sources, and the lack of natural inertia in power electronics-based inverters.

Alternative Fuels (Sustainable Hydrogen, Fuel Cell Technologies)

Conventional fossil fuels are hazardous to the environment due to pollutants' emission during fuel combustion. The release of CO_2 and other pollutants from ground and air transportation and industrial processes harms human health. For example, NOx pollutants are also hazardous, and combined with hydrocarbons and sunlight, give rise to ozone and secondary nitrated hydrocarbons in the lower atmosphere. One of the main challenges in sustainable growth is to discover ways to produce, non-polluting novel alternative fuels with high yield so that it will be possible to replace polluting vehicles by non or less-polluting alternatives. In parallel, energy production from sustainable sources, such as wind and solar, at large scales must be accompanied by large energy storage means. It is also necessary to develop efficient means to produce green hydrogen, and use it as an energy carrier for applications in transportation and as raw material for industrial processes. Finally, there is the challenge to develop materials and processes to utilize biological waste that is accumulated over time in large disposal areas into biofuels.

To advance research and development of alternative fuels we must deepen our understanding of mechanisms for conversion and utilization of energy, novel processes for waste to biomass conversion, materials and technologies for CO_2 conversion into fuels and chemicals, and green hydrogen production and utilization.

2. Sustainable Solar Energy, Solar Fuels, CPV, PV & AgroPV

Although solar energy is expected to be the main source of renewable energy in Israel in the near future, its widespread utilization lags behind the set national goals, due to the challenges of this technology. These challenges include land utilization and land cost (the broad areas needed to collect natural sunlight for large scale electricity production are limited, especially in a small and densely populated country like Israel, and the land cost adds to the balance-of-system costs), intermittent diurnal supply, and weather dependence of the solar radiation flux and spectrum, which causes unstable energy supply.

Furthermore, installation of large-scale energy converting facilities may induce pollution related to the fabrication- and end-of-life procedures of these systems, including large waste volumes and hazardous materials such as lead in solder wires. Efforts are required to develop sustainable manufacturing processes and effective recycling methods. The dissemination of solar-generated electricity to consumers can be a logistical hurdle. Developing efficient transmission and distribution infrastructure is essential to ensure reliable access to solar energy for end-users. Addressing these challenges through research and innovation is crucial for widespread adoption and success of solar energy conversion technologies.

To advance research in this field, it is necessary to establish leading experimental research platforms in solar energy conversion and utilization via which it will be possible to test new solar energy conversion technologies with increased energy efficiency and density. It is also necessary to promote innovation in solar energy harvesting, to reduce current barriers to early installation of new solar power plants, and to integrate solar energy conversion with efficient, low cost storage, such that surplus solar energy can be stored during peak generation periods and used during low production periods, ensuring a stable and reliable power supply. Finally, consumer-reachable large scale (on-site and on the grid) solar energy conversion technologies need to be developed, including solutions for end of life efficient recycling/renovating/reuse of solar systems.

3. **Sustainable Batteries & Electrochemical Energy Storage**
The global shift towards production of energy from sustainable, yet intermittent, energy sources such as wind and sun involve significant challenges relating to energy storage. For example, solar energy is being produced efficiently only throughout 4-5 hours of the day, and excess energy must be generated and stored during these production hours to supply the needs of the rest of the day. In addition, we must build up some backup power, and seasonal storage to address the drop-in production during the winter. As it seems, the only viable solutions at-scale are electrochemical storage solutions: batteries and hydrogen. But despite the great advancement in battery technologies in the past decades, some issues have not been addressed sufficiently, namely sustainability and materials availability. The most developed technology, Li-ion batteries, does not have a cost-effective and carbon-neutral recycling process. In addition, the amount of Li on the earth's crust is limited, and is far from sufficient for large energy storage. Hence, advanced, reliable, and sustainable batteries need to be developed. One promising direction is Na-ion batteries. Another important direction would be to develop cost-effective Li-ion battery recycling processes to retrieve the Li and use it for new batteries.

Israel has a very strong, and internationally recognized community in this field, with a very good track record of collaboration, and real potential to lead future progress in this area. To realize this potential, it is necessary to deepen our understanding of electrochemical processes, durability, and materials science related to batteries (e.g., development of Li-ion recycling and re-use processes), develop technologies for the production of advanced rechargeable batteries that rely on earth-abundant, non-critical, recyclable materials that can be used for large storage applications, etc.

Climate Research Centers

(30M NIS to support 2-4 research centers, maximum 15M NIS per proposal)

1. **Physical Climate System: Understanding Sensitivity and Reducing Uncertainty**
   Elements of the climate system determine our livelihood by controlling the weather, water availability, food security, ecosystem functions, coastal habitability, and many forms of renewable energy. Even small shifts in the distributions of these elements of the climate system can be disastrous and incur extreme costs. Accurate predictions, from hours to decades, are essential for climate preparedness, mitigation, and adaptation. However, predictions of future climate change are rendered uncertain because of several factors, including the inherent complexity of the climate system, limitations on our understanding of the underlying physics, imperfect observations of both present and past climates and methodologies for incorporation of such data in climate models, and limited computer resources for running prediction models that incorporate the currently available knowledge. Major knowledge gaps include the impacts of cloud-aerosol interactions on precipitation and Earth's energy budget, ocean-land-atmosphere-cryosphere interactions, and intricate feedbacks between the elements of the climate system. Together, these gaps render the climate sensitivity to anthropogenic forcing highly uncertain.

   Addressing these challenges requires combining multi-scale observations and a hierarchy of models, which together will generate process-level understanding of components of the climate system, and lead to reduction of uncertainty in climate change projections. Observations of modern climate variables, in situ and by remote sensing, where advanced satellites offer breakthrough opportunities, will form the knowledge basis for the models. Paleoclimate data will constrain the climate sensitivity. Process-level models will provide mechanistic understanding of micro-to-global-scale components of the climate system, and their parameterization in Earth-system models. These models will be able to simulate the complex climate system, and changes to it, under various scenarios of anthropogenic forcing. The resulting data-informed, process-driven simulations will reduce uncertainty in climate change projections, and will help develop efficient adaptation and mitigation strategies.

2. **Extreme Weather Conditions and their Impacts**
   Climate and weather extremes (e.g., heavy rain and snow, strong windstorms, hailstorms, and heat waves) and their impacts (e.g., floods, droughts, and fires) impose high risk to societies and the environment. Attribution of current extreme events to anthropogenic activity, and the prediction of future events on timescales spanning hours, days, months, years, decades, and longer is key to reducing their risk. Several challenges are associated with predicting extremes and their impacts. Extreme weather events are often local phenomena (e.g., flash flood-generating storms), which are not well resolved by weather and climate models. Furthermore, projecting extreme events with climate models is more uncertain than projecting mean conditions.

   Another challenge lies in the prediction of the impacts of extreme events, which highly depend on complex interactions between the weather systems and the surface and environmental conditions. Prediction of extremes also requires a good understanding and characterization of these events, but, by definition, extremes scarcely occur in observational records. Moreover, the frequency of extreme events (e.g., a 100-year event) is a central measure, but standard frequency analysis methods are highly uncertain and thus, detecting changes in extremes with changing climate poses yet another challenge.

Addressing these challenges requires a combination of observations, a hierarchy of models, downscaling techniques, and advanced statistical analysis, including AI methodologies. New observational datasets, obtained in situ and from space, will allow better characterization and modeling of extreme weather events and their impacts. Modeling techniques to be employed include rare-event simulations, sub-seasonal to seasonal forecasting ensembles, and convection-permitting models. Downscaling will involve dynamical and statistical approaches. The meteorological results will be coupled with impact models (e.g., hydrological, agricultural, storm surge) to predict the risks associated with extreme weather events. Some of these approaches require high-performance computing facilities, and investment in such facilities stands to improve research into weather extremes and their impacts in Israel. Finally, advanced statistical methods will be developed for attribution of extreme weather to anthropogenic versus natural causes, and for reduction of the uncertainty in event-frequency estimations.

Biogeochemistry and the Carbon Cycle

Biogeochemical cycles play a crucial role in regulating Earth's climate. The carbon cycle governs the balance between the sources and sinks of atmospheric greenhouse gas concentrations, and the amount of carbon stored in the oceans and on land. Other biogeochemical cycles, such as the nitrogen and phosphorus cycles, also have a role in climate regulation through their impacts on the productivity of the marine and terrestrial biosphere. In turn, biogeochemical processes and rates depend on components of the climate system, resulting in a complex network of feedbacks and forcing. Thus, understanding the ways in which humans affect the global biogeochemical cycles is crucial for accurate projections of greenhouse gas concentrations, the extent and health of forests and wetlands, the Earth's surface albedo, and the sources and sinks of carbon under climate change scenarios. Further, the carbon cycle consists of processes that naturally remove CO_2 from the atmosphere. Harnessing and enhancing such natural processes for the removal and sequestration of anthropogenic CO_2 may offer promising avenues of climate change mitigation.

Future projections and biogeochemical cycle-based climate solutions require an understanding of the interactions between the carbon cycle, and components of the climate system. There are several challenges to achieving such an understanding, including the complexity and variability of the carbon cycle, both spatially and temporally, the importance of ocean dynamics to carbon uptake and storage, the lack of reliable, long-term data on carbon cycle dynamics (e.g., sources and sinks, feedbacks) and their relationship to climate change, and large uncertainty on the future trajectory of climate change itself, and, therefore, its impacts on biogeochemical cycles.

The above challenges are to be addressed by a combination of observations, lab and field experiments, theory, and models over a range of spatio-temporal scales. Experiments and observations (e.g., flux towers, remote sensing by drones and satellites, environmental measurements) will span micro—ecosystem—global scales, to provide high-resolution, high-quality data on carbon fluxes, greenhouse gas budgets, primary productivity, and other aspects of the carbon cycle. The data will be used to generate quantitative models of the marine and terrestrial components of the carbon cycle, the biogeochemical cycles of other elements coupled to it, the ways in which these are expected to evolve under climate change scenarios, and the ways in which they may be employed for climate mitigation. Laboratory-to-mesoscale experiments of climate mitigation strategies inspired and informed by biogeochemical cycles will advance the feasibility and application of such solutions.

Energy-Climate Interactions Research Centers

20M NIS to support 1-2 research centers, maximum 15M NIS per proposal)

Attempts to understand and mitigate climate change, which is largely driven by greenhouse gas emissions from the energy and transportation sectors, face several challenges. Two central scientific challenges are (i) uncertainty in future climate change projections due to the complexity of the climate system (e.g., ocean uptake, multiple feedback loops, natural cycles, socio-economic drivers etc.) and uncertainty in future greenhouse gas and aerosol emission scenarios, and (ii) the issues that limit the development of scalable, cost-effective mitigation technologies to, for example, reduce greenhouse gas emissions, increase energy efficiency, and capture and remove anthropogenic greenhouse gases from the atmosphere into terrestrial and marine storage. Addressing these challenges in an integrated manner rather than in isolation, may offer unique opportunities for scientific breakthroughs and solutions to prevent severe risk. Examples of such opportunities include (i) incorporation of weather predictions into management of solar and wind energy fields, which could increase their efficiency, and (ii) the harnessing and enhancement of processes in the carbon cycle that naturally remove CO_2 from the atmosphere, which may offer promising avenues of climate change mitigation. As an example of risk prevention, reduction of cooling aerosol emissions (e.g., sulfate aerosols) without commensurate reduction in greenhouse gas emissions could lead to rapid warming, and research into this topic could reduce the risk involved.

Addressing the above challenges requires a combination of observations and models of climate system components, which together will provide an understanding and robust predictions of climate and weather aspects that are of specific interest for the development of mitigation solutions. For example, remote sensing observations or in-situ measurements could provide information on components of the carbon and water cycles such as carbon dioxide fluxes in terrestrial systems, or the natural absorption of carbon in the ocean; harvesting carbonates from the oceans may provide a source of carbon and simultaneously increase the absorption of CO_2 from the atmosphere. Finally, regional weather models could help develop renewable energy solutions that consider the expected variance in operating conditions.

It is recommended that energy-climate interactions research centers will promote the following goals: (1) expanding the network of observations of the climate system and biogeochemical cycles at relevant scales for the development of solutions and for examining ways to harness the natural system to reduce climate change, with an emphasis on the removal and capture of carbon dioxide using various methods and environments, and (2) develop and validate models of Earth System components of interest to development of solutions at the relevant scales.

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In addition to supporting research centers mentioned above, the Committee also recommended the establishment of **human capital development programs,** as detailed below:

1. **Start-Up Grants for New Faculty (30 million NIS)**
   One of the most effective ways to advance research in specific directions for years to come is to recruit young scientists with appropriate background and personal commitment to the targeted research areas.
   In light of the above, the Committee recommended the establishment of Start-Up Grants for New Faculty according to the outline below:

   <u>Experimentalists</u>: 1.25 million NIS grant for laboratory equipment + 170,000 NIS start-up research grant.

   <u>Theoreticians</u>: 250,000 NIS recruitment grant + 50,000 NIS start-up research grant.

2. **Postdoctoral Fellowship Program (6.75 million NIS)**
   To boost the new generation of researchers in the field, the Committee recommended the establishment of a Postdoctoral Fellowship Program for outstanding graduates as follows: $120,000 for a 2-year fellowship in a leading institution abroad X 3 fellowships per cycle (= a total of 15 postdoctoral fellowships over the 5 years of the initiative).

Budget (in Million NIS) for a Five-Year Plan (2024-2028)

Energy and Climate		
Research Centers *	Energy (4-8 centers, max. 25M per proposal)	100M
	Climate (2-4 centers, max. 15M per proposal)	30M
	Energy-Climate Interactions (1-2 centers, max. 15M per proposal)	20M
Human Capital	Start-Up Grants for New Faculty	30M
	Postdoctoral Excellence Fellowships	6.75M
Total		**186.75M**