Water Interactions – A Systemic View

Why we Need to Comprehend the Water–Climate–Energy–Food–Economics–Lifestyle Connections

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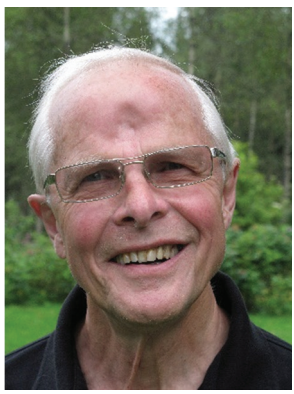
To my own and to the world's grandchildren

About the author



Gustaf Olsson is a professor in industrial automation and since 2006 professor emeritus at Lund University, Sweden. His has devoted his research to control and automation of urban water systems, power production, electrical power systems, and industrial processes. Since his retirement, he has focused on the water–energy nexus: how energy exploration, generation, and use are related to water availability and quality, and how water operations and consumption are dependent on energy. Naturally, couplings to climate change, population increase, and urbanization are crucial.

He was part-time guest professor for more than ten years at Tsinghua University, Beijing, from 2006, and at the Technical University of Malaysia. He is an honorary faculty member at the University of Exeter, UK, and advisor to several international research groups and programs. He has been the editor-in-chief of *Water Science and Technology* and member of the IWA (International Water Association) Board of Directors. In 2010 he received the IWA Publication Award. In 2012 he was the awardee of an honorary membership of IWA as well as an honorary doctor degree at the Technical University of Malaysia. In 2014 he was appointed Distinguished Fellow of the IWA. For almost a decade he has been mentoring IWA Young Water Professionals from all continents.

Gustaf has authored 12 international books (some of them translated into Russian, German, Korean, Chinese and the Persian language), contributed chapters to more than 20 books and published over 200 scientific papers. His book *Water and Energy* first appeared in 2012 followed by a 2nd edition in 2015. With Pernille Ingildsen, he co-authored *Smart Water Utilities: Complexity Made Simple* (IWA Publishing 2016, now open access). His book *Clean Water using Solar and Wind: Outside the Power Grid* was published in 2018 (IWA Publishing, now open access). He has been invited to several countries and international conferences to present results around the topics of water and energy.

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Preface

The desire to understand was the key driving force to write this book. The world is a complex place with a hodgepodge of interacting problems and possibilities. We are facing complex problems like global warming, climate change, water scarcity, droughts, floods, food crises, energy limitations, air pollution, and absurd economic inequalities between nations and people. Complex problems cannot be solved by looking at one component at a time. Most incidents are connected to others. In our world of specialization, solutions require cooperation, mutual respect, and understanding what to expect from other specialists.

The aim of this book is to demonstrate and describe how climate change, water, energy, food, economics, and lifestyle are intimately interconnected. We – all of us in the global village – depend on each other. This has become so apparent during the pandemic from 2020 onwards. Global warming and its impact on climate will affect every continent and nation and there is no vaccine. We must understand these interconnections and act accordingly.

Deniers do not see the connections or do not wish to understand: rain has fallen for the first time on record at the Greenland Summit Station, the highest point on the Greenland Ice Sheet (3216 metres). On 14 August, 2021, the temperature remained above freezing for about nine hours. The warm air caused extreme rain on the ice sheet – the heaviest rainfall there since record keeping began in 1950, according to the National Snow and Ice Data Center at the University of Colorado. Rain in Iceland is another anomaly where deniers do not recognize projections, couplings to climate or further explanations; the rain can be considered just a fun fact. Isolated from fires in Siberia, floods in Germany, glacial melt, calving of icebergs the size of states, hurricane seasons getting longer and longer, outgassing of methane in the tundra, droughts, overwhelming cold snaps, coral bleaching, fires in the rain forests, and then a little strange rain would be nothing but odd weather. So long as all these events

are separated from one another, they can all be explained away. But taken as a whole, they can only be attributed to a fundamental change on our planet.

Over the years there have been several proposals for specific design solutions, control methods, or operational guides in terms of green technology, water and energy efficiency, food production, geoengineering methods, and space settlements on Mars to solve the environmental and resource problems of a finite Earth. Recalling the famous phrase attributed to Einstein, '*we cannot solve our problems with the same thinking we used when we created them*,' we must become aware of the close couplings. An integrated approach to face the complex challenges is necessary. This includes not only innovative technical solutions but several non-technical issues too. It's equally important to address political, organizational, and economic topics. *Changes in our attitudes and lifestyles are crucial* if we wish to create a more sustainable use of natural resources. Saving one MW ('negawatt') is cheaper than producing one. There is a sense of urgency when we see dwindling water resources in many places and when the increasing use of energy will further aggravate climate change.

Our situation today is not an accident – it is the consequence of the way we think and act. We have failed for decades to act, having listened to scientific evidence of climate change and its causes. It is crucial when getting to know the context, to see the connections, listening not only to lobbyists but to people that are affected by the changes. The Covid-19 pandemic has taught us that we have an interconnectedness and mutual responsibility towards one another and towards our Earth. Caring for our fellow citizens and caring for our environment are the same thing. As expressed by Chief Oren Lyons (Native American Faithkeeper of the Turtle Clan, member of the Indigenous Peoples of the Human Rights Commission of the UN, and professor of American Studies at University of Buffalo, New York): '*Man sometimes thinks he's been elevated to be the controller, the ruler, but he's not. He's only part of the whole. Man's job is not to exploit, but to oversee, to be a steward. Man has responsibility, not power.*'

We will describe several examples of our exploitation of nature and our self-destructive behaviour. Again, Oren has articulated: '*The law says if you poison the water, you'll die. The law says that if you poison the air, you'll suffer. The law says if you degrade where you live, you'll suffer … If you don't learn that, you can only suffer. There's no discussion with this law.*'

It has been said many times that we have to listen to science to understand dangers and connections. However, we also must look for and recognize dangers that are not described by natural sciences: greed, apathy, and selfishness. Science cannot provide a moral compass for our actions. This must be achieved by cultural and spiritual transformations and then we have to recognize how our economic systems and our lifestyle are intimately connected to climate, water, energy, and food.

The *mission of the book* is to describe how various objects are related to each other. Unless we understand these couplings, we cannot even start solving the complex problems we face. Various solutions or approaches to solutions presented here will probably not provide any innovative new answers to the

water, energy, food, and economy challenges that we are facing. This herculean task is far too unrealistic for an individual. However, understanding the couplings is an important beginning.

The IPCC Working Group II contribution to the Sixth Assessment Report was released only a few weeks before the completion of this manuscript. It adds further evidence of the enormous threat that the world is facing from climate change but does not change any of the conclusions and statements made in this book. Our attention concerning the current climate crisis and resource challenges must not be pushed into the background because of the Russian invasion of Ukraine. There is a rapidly closing window for climate change action.

Vrångö, Swedish west coast archipelago
March 2022
G.O.

Acknowledgements

For decades I have had the privilege to learn from so many people. They have encouraged me, corrected me, and widened my perspective. I have learnt a lot by guiding 23 PhD and hundreds of MSc students in Sweden, and from several other PhD students while a guest professor at Tsinghua University, Beijing, China; Technical University of Malaysia; and at universities in Johannesburg and Cape Town, South Africa.

Allan R. Hoffman, former Senior Analyst, US Department of Energy, was a most influential source of knowledge when I started studying the water–energy nexus. We have remained in contact for more than a decade, and he has generously shared his knowledge and offered me feedback on my ideas and given me new perspectives.

Gianguido Piani was already my co-author more than 30 years ago. He is one of these exceptional renaissance style people with a wide knowledge, not only in technology, but in humanities and language. Having lived in many countries working as an energy and automation specialist, he has given me plenty of new outlooks and a lot of constructive feedback.

Lars Gertmar, my professor colleague at Lund University, Sweden, since the early 1990s, has generously spent a lot of effort to review, correct, and challenge me, given his extensive experience in all kinds of aspects of energy transition, from both industrial and academic environments.

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Cello Vitasovic, Los Angeles, USA and Pernille Ingildsen, Denmark, have been my close collaborators for a long time. I first met Cello when he was a PhD student more than 40 years ago. Pernille was my PhD student more than 20 years ago. Our cooperation has continued over the years and resulted in several publications. Both Cello and Pernille have given me a lot of inspiration, joy, new perspectives, and courage to proceed with this work, and have through the writing project offered me many good ideas on how to make the content more relevant.

Lawrence Jones, Vice President International Programs, Edison Electric Institute, Washington DC, USA, and I have had regular contacts for more than two decades. Lawrence has a true global perspective and knowledge that is a key prerequisite to solve complex problems. His experience and feedback have been invaluable to me in my writing.

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Mia Engstad and Mikael Engstad in Sweden made me aware of and demonstrated the potential of regenerative farming. This motivated me to study this crucial topic and gave me new perspectives on food production.

Jing Liu has managed to use his scientific knowledge in biotechnology and automation in combination with his leadership of a successful company (BPC Instruments, Lund, Sweden). I have learnt a lot from him during two decades of cooperation.

Margareta Ingelstam, Swedish author and educator, is a pioneer and veteran in the work on peace and nonviolence and a great role model. During the past year I have had the fortune to work closely together with her to explore how experiences from the peacebuilding movement can be applied to education and empowerment on Climate Justice and Climate Security.

And all of you that helped with your conversations, ideas, and encouragement (in alphabetic order): Per Duregård, Lars Fränne, Ulf Jeppsson, Leif Nilsson, Lars Odén, Lars Gunnar Sundin (all from Sweden), Zaini Ujang (Malaysia), and Peter Vanrolleghem (Canada).

I had no plan to write a book like this when Mark Hammond, Books Commissioning Editor at IWA Publishing, in 2021 encouraged me to write some extension of my previous books *Water and Energy* and *Clean Water Using Solar and Wind*. One probably must be foolhardy to accept, but I could not resist the temptation to try. I wish to thank the cooperative and friendly staff at IWAP.

Kirsti, my patient, incomparable wife, miraculously loves me despite my odd habits of work. Regularly I ask her advice how to describe various phenomena concerning climate, water, energy, and lifestyle. Without her support and understanding I could not have finished this work. And more essential, she provides me with a more complete perspective of life.

And you, my children and grandchildren, you have motivated me to write the book. I tried my best, thinking of your future.

Prologue – Some experiences in my lifetime

What has been will be again,
what has been done will be done again;
there is nothing new under the sun. Ecclesiastes 1:9

The awareness that Mother Earth has limited resources is not new. During my life I have gradually learnt how nature, resources, industrial development, and lifestyle are interconnected. I have discovered that at the age of 80+ years I see events and experiences in life in context in a way that I didn't when I was younger. This prologue is a subjective narrative from my lifetime and how I experienced pathways toward today concerning the state of water, energy, climate, population, and food. My aim is to set the scene of today, providing some background information for the rest of the book.

I have lived a privileged life. My family was not wealthy, a typical middle-class Swedish family. Still, compared to most people in this world we have been fortunate. I was born in 1940 in Sweden, in the second year of World War II. Finland was fighting the Soviet Union; some 70 000 Finnish children were brought to Sweden to escape the war (my wife was one of them). Germany had invaded Norway and Denmark, while Sweden managed to escape getting involved in the war. The German offence in Western Europe continued. The Battle of Britain was initiated by Hitler. A Swedish textbook on the German language had the text '*Der Führer hat Ordnung geschaffen*' (The leader Adolf Hitler has created order). Towards the end of the 1940s the text was changed to '*Gott hat die Welt geschaffen*' (God has created the world).

1940 global population: 2.4 billion
Global CO_2 concentration: $\cong 280^* + 20 = 300$ ppm
(parts per million or mg/l)
*= the pre-industrial level

There was a great shortage of gasoline in Sweden during the war and towards the end of the year 1940 all private consumption of gasoline for cars was forbidden. The cars had to be fuelled with wood gas. Towards the end of the war in 1945 I was sufficiently old to remember the wood gas container mounted on the back of our car. There was a special smell of burning and my father had some dirty gloves to handle the container. Fossil fuel consumption was dominated by coal, and our apartment building was heated by coal for the whole decade. I recall how coal was delivered to our building in sacks made of jute fabric. The delivery men were really dirty. Later, when coal was replaced by oil it was praised as a truly clean solution for heating. I was reminded of my childhood when I was working at Tsinghua University in Beijing after 2006. Then the university was still heated by coal. However, all coal-powered energy now has been replaced by natural gas in Beijing.

Many years after my childhood, I studied the geopolitical importance of oil and particularly how energy and oil capacity was a decisive factor in World War II operations. Trucks, tanks, cars, and airplanes needed gasoline. Refined oil was used for making TNT in bombs and synthetic rubber for tyres as well as a lubricant for all kinds of machinery. The American oil industry played a remarkable role by supplying the Allied forces with oil. During the 1930s the USA had provided 50% of the global oil supply. Oil tankers had been easy targets for German submarines between the Mexican Gulf and the US East Coast. In the early years of World War II two pipelines were built from Texas to the East Coast. They were protected from enemy attack. Oil from the USA provided some 85% of all the oil – around 1.1 billion (10^9) m^3 – used by the Allied Nations during World War II. An apparent reason for the German Army operations in northern Africa led by General Erwin Rommel was to capture the Suez Canal. This would ensure the route to the oil fields of the Middle East. A major driving force for Hitler to invade the Soviet Union in 1941 was to capture the Soviet oil fields in the Caucasus Mountains. This would have given Germany the necessary oil to fuel the German war machine. The German Field-Marshall Karl Gerd Von Rundstedt admitted after the war that German deficiency in oil was a key reason for losing the war.

Also, the War in the Pacific was fundamentally a war over oil resources. Japan lacked its own oil supplies. The USA had been alarmed by Japanese aggression in Asia and all US oil shipments to Japan were ordered to cease in August 1941, four months before Pearl Harbour. Japan invaded colonial Indonesia in March 1942, occupying the Dutch oil fields. For the rest of the war American submarines waged unrestricted attacks against Japanese oil tankers in the Pacific.[1] Today, as we expand solar and wind, the geopolitical importance of oil ought to decrease.

Even if Sweden was spared from the war there were several consumer restrictions. Private citizens had ration stamps for meat, coffee, sugar, and many other food products. I can vividly recollect my mother telling us to appreciate some special food.

Before I was 5 years old we once travelled some 300 km to the west coast of Sweden. My father was in the military protecting the Swedish border and my mother brought my two elder brothers and me for a short vacation at the seaside. Since travelling was limited also after the end of the war this was felt like an exclusive experience.

In 1948 the family had purchased a little house for summer vacations, located only 8 km away from our town apartment. This meant we all could use bicycles, even if I was only 7 years old. I have clear memories related to water, energy and food. Our town had no biological wastewater treatment plant, and most of the untreated effluent water was flowing into the lake Hjälmaren where we used to swim. My older brother developed serious eczema caused by the polluted water and could not swim for the whole summer. We were reminded all the time to turn off the light when we left any room. Beef was a luxury that we sometimes could get on Sundays.

Since my childhood there has been an incredible development in mobility, which is also reflected in my own life. The family trips until I was almost 15 years were limited to one or two 200 km trips per year to my grandparents. A good friend in my hometown won a competition and earned a trip to Brazil in 1955. This got the attention of the local newspaper and the sensational information that she should bring swimwear in the Swedish winter! My first visit outside Scandinavia took place in 1964, during my fourth year at the Royal Institute of Technology, when we made a study tour by train to Paris and Geneva. Charter flights made travelling by air affordable and in the 1960s we could fly to the Canary Islands in 8 hours in propeller-driven airplanes. Since 1970 I made at least one intercontinental flight every year until I had around 200 flight hours in a year. This made me realize that I was part of the climate problem. Now I have minimized flying, and every trip has to be highly motivated from a climate point of view.

By 1950 I can recall the grown-ups talking about the industrial development after the war. Smokestacks became symbols of development. However, we became aware of air pollution quite early. Close to my hometown an oil shale industry had been established during the war since all import of oil was restricted. The furnaces in Kvarntorp produced as much as 100 000 m^3 of oil annually. We could smell the air pollution and we saw the slag heap growing. The ash was hot when it was dumped on the heap, some 600°C, so the burning hill emitted a very particular smell. This childhood memory gave me some understanding of pollution caused by fossil fuel extraction. The hill is more than 100 metres high and is now an attraction, being the highest point in the county of Närke in mid-Sweden.

1950 global population: 2.54 billion.
Global CO_2 concentration: $\cong 280 + 28 = 308$ ppm

During the 1950s the cold war influenced a lot of discussions and fear of a nuclear war was obvious. However, in 1955 a landmark conference was organized by UN, the 'Conference on the Peaceful Uses of Atomic Energy'. This Geneva meeting was the largest scientific meeting ever held, with an estimated 25 000 participants. For me personally it determined my early career. Nuclear power was apparently going to save the world and 9 years later I got my first employment at the Swedish State Power Board (now Vattenfall) as a nuclear engineer.

I comprehended the geopolitical power of oil for the first time in 1956. The Suez crisis started in October, when Israeli armed forces pushed into Egypt toward the Suez Canal after Egyptian president Nasser had nationalized the Canal that controlled the import of two thirds of the European oil. This created a gasoline crisis in Sweden and elsewhere. No private cars were allowed to be used from Saturday night until Monday (Saturday were working days at that time). Our teenager group enjoyed the car-free weekends and the opportunity to walk anywhere in the middle of the main road.

Alarming accidents in Japan got the world's attention in 1956. A lot of people had been seriously sick and even died due to severe mercury poisoning. For years we had noticed with admiration how Japan had raised itself from the catastrophe of the war and developed industrial production at a rate never seen before. Suddenly this picture became stained. Years later we understood the reasons behind and the chain of processes that triggered the tragedy. The diseases and deaths were caused by methylmercury – an extremely toxic organometallic cation $[CH_3Hg]^+$ – in the industrial wastewater from a chemical factory in Minamata, located on the west coast of the southern Japanese island of Kyushu. The plant had been in operation since 1932 and continued its production until 1968. Some of the mercury sulfate in the wastewater bioaccumulated and biomagnified in shellfish and fish in the Bay and the sea. The local population ate the seafood and got mercury poisoning. Almost 2000 people had died, and several thousand people were the victims. For more than a decade the authorities neglected the problems and did little to prevent the epidemic. The Minamata disaster was a wake-up call that reckless industrial production has a huge price, most often not paid by the industry owners or the customers.[2]

By the end of the 1950s we were experiencing great optimism about the future. I have a vivid memory of 4 October, 1957, when the Soviet Union launched Sputnik. This was the inauguration of the Space Age, and for a 16-year-old boy this was the realization of science fiction. The satellite circled Earth once every hour and 36 minutes. It was clearly visible before sunrise and after sunset. Our local newspaper published a daily update of the times when Sputnik would be visible. The park near our home was packed with people waiting to see Sputnik. My mother did not believe that man should be in space, so she considered the whole spectacle as fake, at least for the first few weeks. Sputnik initiated the space race, and the USA were caught off-guard by the Soviet technological achievement. John F. Kennedy was elected president in 1960 and became the great hero among young people. Moreover, he declared to 'send a man safely to moon before 1970'.

1960 global population: 3.0 billion
Global CO_2 concentration: $\cong 280+36=316$ ppm (the first CO_2 measurements were initiated by Charles David Keeling at Mauna Loa Observatory, Hawaii, March, 1958)

The 1960s was also a decade when Earth's limitations were realized and debated.

I have childhood memories of how we used DDT at home to spray in the closets to get rid of the common clothes moth. The memory of the smell is distinct. It was considered an efficient way to protect our clothes. In 1962 Rachel Carson published her revolutionary book *Silent Spring*. It documented the indiscriminate use of pesticides and accused the chemical industry of spreading disinformation, and public officials of accepting the industry's marketing claims unquestioningly. There are several similarities between this discussion, the dispute about the tobacco industry, and today's debate around climate change and the fossil fuel industry.

In Sweden, much less known internationally, the author Elin Wägner (1882–1949) had published the book *Fred med jorden* (Peace with the Earth) already in 1940, during World War II. She wrote about 'the demands from health and conscience' and criticized the exploration of nature, agricultural land, and human resources, long before ecology and environment were recognized by the general public. Since the World War I she had shown in more than 30 books and numerous articles that three views are closely related: gender equality, peace, and our environment. They depend on each other. Inequality causes war, war destroys human beings, and the environment is ruined if we believe that we can dominate and exploit nature.

In 1965 the Sholapur district in Maharashtra, India, suffered a severe drought having had no rain for 3 years, forcing people to move, causing a crisis in food production, and emergency slaughter of cattle. The Maharashtra Government contacted the Swedish Covenant Church (Svenska Missionsförbundet) to ask for help. A cooperative effort was initiated, called '1000 wells for India' where the Swedes collected money in their churches and sent volunteers to help. One of the pioneers was Oscar Carlsson together with his wife Ingrid, working in education in India.

Oscar became the leader of a foundation called Sholapur Well Service (SWS). On top of the well digging and drilling the little workshop manufactured hand pumps. Oscar was also an inventor and gradually developed a better pump design, the SWS pump, later pictured on an Indian stamp with the text Safe Water. Well number 1000 was completed in 1974. Lead by the Hindustani Covenant Church more than 3000 wells had been

completed in 1986. The pump was recognized by UNICEF as a most reliable and cost-effective hand pump, called India Mark II. More than 3 million pumps have been produced and have been used all over India and in more than 50 other countries. Oscar never filed for a patent but wanted the pump to be freely available to anybody in need. He was the first individual to be awarded 'The Swede of the year in the World' in 1968. I had the privilege getting to know Oscar. In 1981 I got the opportunity to visit Sholapur - invited by another Swedish couple, Eva and Georg Smedberg, working unselfishly for the non-privileged people – to attend the ceremony in a village where a new pump had been installed. Hundreds of villagers had gathered around the well. To see the first flow of water coming out from the hand pump is one of my most unforgettable moments.

Of course, electric pumps made it possible for so many more people to get access to water. However, replacing hand pumps with electric pumps has created a new problem of overuse.

The global annual population growth rate had increased from around 1% after World War II to around 1.8% in the early 1960s. This naturally caused a lot of warnings about the challenge of feeding a large population. Paul R. Ehrlich, an American biologist (with the speciality of entomology, the study of insects) warned about the consequences of population growth and limited resources. In his early career he had been inspired by *Road to Survival*, by William Vogt, published in 1948. This was an early warning of the dangers of overpopulation. Ehrlich published his controversial book *The Population Bomb*[3] in 1968. The first sentence defines the tone: '*The battle to feed all of humanity is over.*' He suggested that various population control methods should be used, such as including 'various forms of coercion' such as eliminating 'tax benefits for having additional children,' to be used if voluntary methods were to fail.

In the decades after Ehrlich's alarm there has been a decline in the *growth* rate, as shown in Figure 0.1. The *fertility* rate for a zero-growth population is 2.1% and has decreased from 5.0% in 1950 to 2.4% in 2021. During the last 5 years the decline has been 0.4% per year. The UN predicts that the population growth rate will decline towards zero at the end of this century.

Georg A. Borgström (1912–1990), a Swedish scientist, geographer, and ecologist, devoted his research to the global hunger problem. He was a professor in plant physiology and an international authority on food production. During the 1960s and 1970s he published several books on food resources, with titles like *The Hungry Planet, Food for Billions, The Food and People Dilemma*, and other studies on the Earth's ecological limitations. Maybe the most famous book is *Gränser för vår tillvaro* (Limits to our Existence). He also described 'the great unfair state' as Europeans seized rich agricultural lands in America and Africa and were fishing all over the oceans. He claimed that Europe could get sufficient food only because of these 'ghost land areas'. Europe exported cereal products but could import protein-rich food. His ideas are still convincing.

During the following decades the green revolution took place, and the use of fertilizers and pesticides increased significantly. Huge irrigation projects increased food production, and as a result the food crisis has developed into

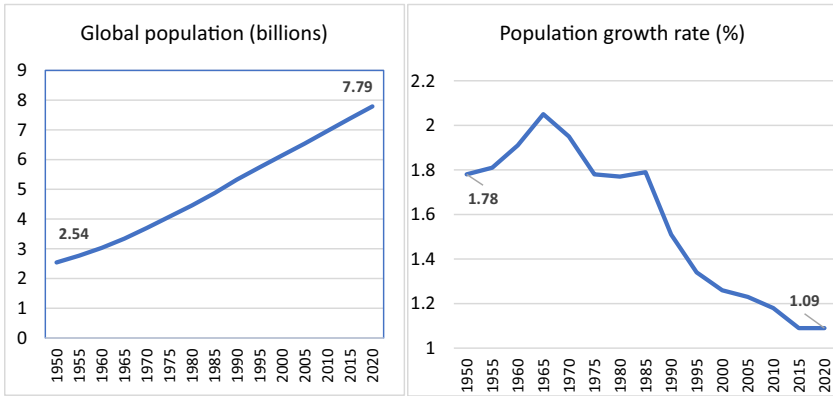

Figure 0.1 World population development since 1960.[4] The growth rate (5-year averages in the diagram) reached its maximum of 2.1% in 1968 and is down to 1.03% in 2021, the same level as before 1940.

a water resource crisis, where more than 70% of the global water use is for food production. However, the water crisis in fact had been a central theme in Borgström's early publications. He also noted that '*to increase the food production has demanded much more water than earlier normal harvests. A large part of the increased production has been bought with water that otherwise would replenish the groundwater. In Western Europe the increased harvests since early 1900 correspond to some 30–50 mm annual precipitation. Thus, the increasing harvests mean serious plundering of water reserves*' [my translation from Swedish]. Borgström also emphasized that those who recommend fast industrialization of the low-income countries often ignore the fact that this requires water availability beyond available limits. He stressed the fact that irrigation will disturb the natural water balance. Often irrigated land can be destroyed alarmingly quickly by salt formation, and he showed cases from places as different as Utah and Iraq.

It is not a new discovery that water reservoirs are causing health problems. Large water basins are sources for certain diseases, carefully described by Borgström in the 1960s. Malaria is the most well-known example. The malaria mosquitoes had already developed resistance to the pesticides being developed. An even larger threat came from the parasite disease bilharzia. In the 1960s some two thirds of the population in the Nile Delta were infected. The eggs are distributed in water and need various kinds of snails as hosts to hatch the larva. Before the Aswan dam was built there was an annual dry period that eliminated a large portion of the snails. Permanent irrigation made the snails thrive. So Borgström's early key message was to combine the technical innovations and developments with a biological framework.

The cost for oil transportation became apparent for us in 1967. The tanker *Torrey Canyon* – a huge ship of almost 300 metres length – ran aground off the

Cornwall west coast in the UK, spilling an estimated 94 000–164 000 m^3 of crude oil. At the time *Torrey Canyon* was the world's worst oil spill and it got a lot of media attention. This was the first supertanker accident, and it raised awareness of the risks of oil. To limit the consequence of the oil spill it was decided to set the wreck on fire by means of air strikes until the ship would sink. To achieve this, some 1500 tons of napalm and 45 m^3 of kerosene were used.[5]

Unfortunately, more accidents followed. In 1978 the *Amoco Cadiz* sank near the northwest coast of France and spilled some 260 000 m^3 of crude oil. This became the largest oil spill from an oil tanker in history.[6] Our oil dependence remains dangerous.

On 21 December, 1968, Apollo 8, the second Apollo mission, left Earth with the purpose to circle around the moon. Nobody had seen the back of our moon before and now we could see it during Christmas. And we saw the Earth appear behind the horizon of the moon. This picture, more than anything else before, symbolized our precious, vulnerable, fragile home, our only home.

Maybe the moon landing on 20 July 1969 will be one of the few memories of the 20th century. This was the highlight of the NASA Apollo programme and the fulfilment of President Kennedy's promise in 1961. To achieve this, Congress had to increase the NASA budget 20-fold. The price to pay troubled Kennedy when in a speech at Rice University in September 1962 he tried to motivate his citizens to make sacrifices: '*We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard; because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one we intend to win*'….., and his famous '*Ask not what your country can do for you* ….'. Maybe this should be a guideline for our decision makers when addressing the global warming challenge.

I spent the academic year 1970–71 as a postdoc at University of California, Los Angeles (UCLA) at the Systems Science Department. It gave me a deeper insight into systems thinking. A system is more than its parts or components. Interactions rather than parts in isolation must be considered. I also understood better how the same type of thinking can be used not only in technical processes but also in areas like astronomy, economics, sociology, and medicine. This insight has inspired me in my attempts to understand the nexus that is the topic of this book.

1970 global population: 3.7 billion
Global CO_2 concentration: $\cong 280 + 45 = 325$ ppm

From a personal point of view the year in Los Angeles presented a lot of sobering experiences. Flying in over LA for the first time gave me an almost desperate feeling when I saw the smog over the metropolitan area. Our younger son was only one year old, and he soon caught asthmatic bronchitis during our visit. The advice from the paediatrician was clear and distinct; my son could

only recover if we moved away from LA. Naturally this gave me a lot of guilt. To my relief, after we had moved back to Sweden after our year he recovered quickly. We had lived close to the Interstate 405 having four lanes in each direction and saw the demonstration of sources of the smog all the time. The gasoline was so cheap that it was not considered a real cost and was regarded almost as a birthright. The gas mileage of the cars was lousy, typically 12–13 miles/gallon (or 20 litres per 100 km). That was acceptable because gas was cheap and abundant. We paid 28 cents/gallon. In Sweden the price was around 2.5 times higher at the time. Taking the price index into consideration today's price is around 5.5–6 times more expensive than the LA price in 1970 and the Swedish gasoline price is still some 2.3–2.5 times higher than the US price. Also today, transportation is a major source of greenhouse gases in the US economy. The spirit of the times in the USA may be illustrated by a speech by President Richard Nixon in 1973: '*We use 30 percent of all energy ….. That isn't bad; that is good. That means that we are the richest, strongest people in the world and that we have the highest standard of living in the world. This is why we need so much energy, and may it always be that way*.'[7]

In 1970 we learned about the city of Seveso in Italy, some 20 km north of Milan. The name became a synonym for highly toxic dioxin, caused by another case of careless industrial production. At least 2000 people in a large area of the Lombard Plain were made sick by a dioxin cloud after an accident at a chemical plant in Seveso. Some 80 000 animals were slaughtered to keep the poison from entering the food chain. More than 10 years later Europe adopted the Seveso Directive, regulating the manufacture and storage of hazardous materials.[8]

In 1973 I began my research on water and wastewater treatment automation. Design and operation of wastewater treatment plants had traditionally been carried out only from a steady state point of view. In other words, only average loads and flow rates were considered, not the significant dynamic variations of the load over hours, days, and weeks. My control approach was considered with great suspicion by 'traditional' civil engineers, claiming that I did not really understand the real problems. Learning about water problems got me much more interested and involved in environmental thinking.

We had been aware, from World War II and during the Suez crisis in 1956, of the geopolitical consequences of oil. In the fall of 1973, we experienced another oil crisis. This time the OAPEC countries (Organization of Arab Petroleum Exporting Countries) proclaimed an oil embargo. The embargo was a consequence of the October war in 1973 between Israel and a coalition of Arab states, mainly Egypt and Syria. The Sinai Peninsula and the Golan Heights had been occupied by Israel in 1967. Egypt had the initial aim to gain control of the eastern bank of the Suez Canal to get full control of the Canal. On 6 October, the Jewish holy day of Yom Kippur (this is the Day of Atonement, a most important holiday in the Jewish faith), the Arab forces launched a surprise attack against Israel, both towards Sinai and the Golan Heights. The OAPEC embargo was aimed at nations that supported Israel during the October war. The embargo lasted until March 1974, causing the oil price to increase almost three-fold. This caused an oil crisis with several consequences on global economy and politics.

The 1973 oil crisis has been followed by more oil shocks, having impacts all over the world. The Iranian revolution in 1979 caused just a 4% drop in oil production. Still the political uncertainty caused the oil price to almost double over the coming year. In 1980 Iraq's oil production dropped significantly because of the Iran–Iraq war. This also created economic recessions all over the world. However, the development of solar photovoltaic and wind power over the last few years raises the hope that energy will become less influenced by geopolitical forces, when the 'fuel' is available all over the place. This is discussed elsewhere.[9]

In 1973 Ernst F. Schumacher (1911–1977) published his landmark book *Small is Beautiful*.[10] Schumacher was an economist from Oxford and described our economic systems and their purpose. He challenged the current state of excessive consumption in our society. He wrote and talked about 'natural capital' and chose fossil fuels as one example. We are treating them as income although they are undeniably capital items. He explained:

> *If we treated them as capital items, we should be concerned with conservation: we should do everything in our power to try and minimise their current rate of use; we might be saying, for instance, that the money obtained from the realisation of these assets – these irreplaceable assets – must be placed in a special fund to be devoted exclusively to the evolution of production methods and patterns of living which to not depend on fossil fuels at all or depend on them only to a very slight extent. … We are not in the least concerned with conservation; we are maximising, instead of minimising, the current rates of use; and, far from being interested in studying the possibilities of alternative methods of production and patterns of living – so as to get off the collision course on which we are moving with ever-increasing speed – we happily talk about unlimited progress along the beaten track, of 'education for leisure' in the rich countries, and of 'the transfer of technology' to the poor countries.'*

We had the oil crisis in 1973 in vivid memory.

Too many economists had made us believe that all problems can be solved by printing more money. Yet, money cannot be eaten. At the end, someone must grow the food that we are eating. We burn fossil fuels and use resources that we have not produced. It is like spending money that we won in a lottery. Schumacher warned that the modern world must balance economic growth with the human costs of globalization. In 1995 *Small is Beautiful* was ranked as one of the 100 most influential books published since World War II'.[11] Schumacher's ideas are still my source of inspiration.

In 1974 I got acquainted with another important message: *The Limits to Growth*.[12] A group of 30 individuals from ten countries had gathered in Rome, at the instigation of Dr Aurelio Peccei, an Italian industrial manager affiliated with Fiat and Olivetti,[13] to discuss the present and future predicament of human beings. The participants were scientists, industrialists, educators, economists, humanists, and civil servants. Out of this meeting grew The Club of Rome.

They initiated their study under the leadership of Professor Dennis Meadows at Massachusetts Institute of Technology (MIT). They got a lot of inspiration from Professor Jay Forrester (1918–2016) of MIT, a pioneer in systems engineering. In 1971 Forrester had presented his book *World Dynamics*, including an extremely simple mathematical dynamical model of the world, consisting of just five differential equations.[14] His previous publications included books on *Industrial Dynamics* and *Principles of Systems*, describing the foundations of systems engineering. In *World Dynamics,* world development was described by the five variables: (1) world population, (2) pollution, (3) amount of irrecoverable natural resources (such as fossil fuels), (4) world capital investment, and (5) percentage of capital invested in the agricultural sector.

Forrester was already famous for his research in electrical and computer engineering during the 1940s and early 1950s. Forrester had invented the addressing system for digital computer memory. In the early 1950s he was appointed as head of Project Whirlwind, the team at MIT that built one of the first digital computers. Forrester figured out a way to organize the magnetic cores that stored information into a grid so that their contents could be retrieved. This was a true foundation of the modern computer.

Forrester was almost surely aware of the limitations of his world model. He used birth and death rates for high-income and low-income countries, based on available statistical data. Obviously, he did not predict all the advancement made later in medicine and public health. He calculated the impact of pollution but could not know how water treatment would progress. Many of the parameters and coefficients of the model are truly time varying, giving the predictions great uncertainty. Now, 50 years later we know several parameters that Forrester could not have known. For example, he predicted that the global population would peak at a little more than 5 billion in 2020. However, Forrester did not pretend to present quantitative predictions of the fate of Mother Earth. Rather, he wished to demonstrate the power of system dynamics to make predictions. The world would certainly collapse as a result of unlimited growth.

Dennis Meadows and his students developed a slightly more complex world model,[15] but the general performance was like Forrester's model. The book *Limits to Growth* was published in 1972 and received enormous attention. However, I was sceptical of the predictions – having not included uncertainty – to the year 2100 based on data from the first half of the 20th century. The qualitative message was clear but by showing quantitative simulations as if they were true reduced the credibility of their message. Notably, Forrester himself did not participate in this study. It taught me how dangerous it is to present quantitative results that are not well founded. Trust in the rest of the message may be lost, even if it was obvious that we cannot have unlimited growth, just as Schumacher and Forrester had said.

In 1975 I spent a sabbatical semester at the University of Houston, Texas. Professor John F. Andrews (1930–2011) was my host in Houston and one of the true pioneers in understanding wastewater treatment processes as dynamic systems. This was a most rewarding visit where I learnt a lot of process technology from John while he eagerly wanted to learn more about

my experiences of automatic control. This led to a life-long cooperation and friendship. I had brought a picture from a Swedish weekly magazine to my colleagues in Houston, showing our capital Stockholm. In the foreground a number of people were swimming in Lake Mälaren in the centre of Stockholm, where the Town Hall was seen in the background. The clean water in downtown Stockholm drew a lot of attention and was a clear demonstration that biological wastewater treatment around Stockholm had been so successful that the lake was sufficiently clean for swimming. This picture became a main justification for partly locating the next International Water Association (IWA) specialized conference on instrumentation, control, and automation in Stockholm in 1977. Forty years later we would summarize the development and the experiences in instrumentation, control, and automation in wastewater treatment.[16]

During my stay in Houston a special symposium was organized on the theme 'limits to growth' with only invited people. I had the fortune to represent the University of Houston. Dennis Meadows and his colleagues in the Club of Rome were invited speakers to the symposium. Their serious message disturbed me not only by their confident predictions but by the fact that the team arrived in large limousines to talk about limits to growth. I learnt the lesson that *we must live the message*.

Also E. F. Schumacher was attending the symposium, and for me he made a long-lasting impression. His message was that we must build our economies around the need of communities and people, not of corporations. This was quite a provocative message in Houston, the oil and gas metropolis that was expanding like never before. Since his presentation in Houston in 1975 the CO_2 emission rate has increased about 2.5 times.

From Schumacher, I also got my first insight into sustainability, even if I did not use the term in 1975. He mentioned a second aspect of our limited resources: the tolerance margins of nature. Since my encounter with Schumacher, I have studied many aspects of our limited planet: water resources and water scarcity, polluted waters, dams from mining operations, limited resources of vital substances like phosphorus, and waters and wetlands that have been devastated by oil operations. They are all aspects of the sustainability concept. Several of them are included in earlier books and publications on water and energy.[17]

Rachel Carson and Paul Ehrlich had made us aware of the interconnections between the environment, economy, and social well-being. In 1972 the UN Conference on the Human Environment took place in Stockholm and naturally got special attention in Sweden. The conference was partly motivated by the pollution and acid rain problems of northern Europe, and it led to the establishment of the UN Environment Programme (UNEP). Naturally the oil crisis in 1973 fuelled the limits to growth debate. It was not until 1987 that the World Commission on Environment and Development (WCED) (called the Brundtland commission) formulated the concept *sustainable development* to general acceptance.[18]

Despite the world oil crisis in 1973, energy was still cheap in Texas in 1975. Air conditioning was truly necessary in the summer heat with 37°C and 100% humidity. During a weekend trip we went to a pizza place to eat. We experienced the temperature shock of entering the cool restaurant. The illumination was

dim and after a while I discovered a fireplace with a real fire burning! The idea was to make the room a little cosier. The combination of air conditioning and fire became my symbol of energy waste. Very few people around me in Houston at that time understood my excitement about the waste of energy.

Over the years there has been a multitude of definitions of sustainability and there is still no scientific or political agreement on how to define sustainable development. My attitude has been that there is a combination of necessary developments to preserve our earth, our environment, and the resources that we have to use. It is closely related to our lifestyle and our consumption. For many people 'sustainable development' is defined like 'democracy' in the sense that it is 'universally desired, diversely understood, extremely difficult to achieve, and won't go away'.[19]

How does our economic system impact the way we live? Does it really affect what we truly care about? Schumacher seriously questioned the idea of unlimited growth, 'more and more until everybody is saturated with wealth'. We know that the environment will not be able to cope with the burden of growth. Modern economy is driven by greed and envy and Schumacher claimed that the inevitable result is 'nothing else than a collapse of intelligence'.

Exxon, the large Oil and Gas Company, was aware of climate change as early as 1977, 11 years before James Hansen told the US Congress about climate change in 1988 (see below). This sobering message was delivered by senior scientist James Black.[20] Still, this did not prevent Exxon from refusing to acknowledge climate change for decades and even worse, promoting climate misinformation. They had learnt from the way the tobacco industry had spread lies regarding risks of smoking.[21] They knew, once the world understood the risks, their products would not remain profitable. In 1978 Black warned Exxon that a doubling of CO_2 in the atmosphere would increase the global average temperature by 2–3°C. This is in good agreement with scientific results today. His warning came more than 40 years ago: '*present thinking holds that man has a time window of 5–10 years before the need for hard decisions regarding changes in energy strategies might become critical*.' Not many people listened. Exxon supported the creation of the Global Climate Coalition in 1989 (disbanded in 2002) to question the scientific basis for concern about climate change. It also helped to prevent the USA from signing the Kyoto Protocol in 1998 to control greenhouse gases. Actually, the USA with Al Gore as Vice President did sign the Protocol, but Congress did not ratify it. The USA had put as a condition for their signature the introduction of marked-based mechanisms (emission trades), while Europe was for planned control with regulations and investments. The Kyoto Protocol was criticized as having several inconsistencies and outright design flaws that seriously hinder its effectiveness. Later, in 2009, James Hansen officially criticized the Kyoto Protocol as an inefficient and indulgent 'cap and trade' system. Detailed criticism had been published earlier by Gianguido Piani.[22] Hansen stated in 2009 that 'the developed nations want to continue basically business as usual, so they are expected to purchase indulgences to give some small amount of money to developing countries'. Hansen preferred a 'carbon tax', not the Kyoto 'cap and trade' system.

Also, hydropower comes with an environmental cost. My father was a building contractor, so I was introduced early to building houses. Even if he did not build roads and bridges, they caught my interest very early, so as a 6-year-old first-grader I had heard about the Royal Institute of Technology in Stockholm and I made up my mind to 'become an engineer and earn a lot of money'. Early on I admired large hydropower dams. The marvellous engineering work to build these huge structures to provide electrical power for us made a great impression on me. In my country, Sweden, some 45% of our electrical power is today produced by the hydropower systems in the north of the country and then transmitted via huge power transmission lines to the main consumers in the south. I still remember when my father in the 1950s showed me the power line coming from the Harsprånget plant in the far north providing power for us more than 1000 km further south. At that time the power line was the world's longest power line with 380kV (now 400 kV) voltage. It was many years later that I realized that hydropower also comes with an environmental cost. In 1975 the Banqiao Dam (in Henan Province, China) failed due to extraordinarily heavy precipitation caused by a typhoon, combined with poor quality construction of the dam, which was built in the early 1950s. The flood immediately killed over 100 000 people, and another 150 000 died of subsequent epidemic diseases and famine.[23]

1980 global population: 4.5 billion.
Global CO_2 concentration: $\cong 280 + 59 = 339$ ppm

My first real challenge to discuss science with the general public took place in 1980. The nuclear power issue had become a true watershed in Swedish politics. The Harrisburg Three Mile Island nuclear accident had taken place in the year before and caused an increasing opposition against nuclear power. The Swedish Government arranged a referendum on nuclear power. Having worked as a nuclear engineer I got invited to take part in some public discussions. I did not want to argue for or against nuclear power, but instead wanted – to the best of my knowledge – give scientific reasons both for and against, inspired by the physicist Richard Feynman.[24] My first disappointment was that so few experts wanted to get involved in the debates. Some of them were prevented by their employers. Many engineers did not wish to discuss the issue since they claimed that they did not understand the complexity of nuclear power: 'I just work with nuclear core material', or 'I only know about turbine issues', etc. So, most discussions took place between laymen. I also realized that the scientific method is a handicap in a debate before an audience that is not an expert in science. The audience did not like 'on one hand' and 'on another hand'. They wanted a clear-cut message. So I realized that a lawyer-style message will win over a scientist-style message. This became a life-long lesson: as professional researchers we must learn how to communicate science results to the public and policy makers.[25] At the time I believed that knowledge is power and should decide the logical and ethical grounds on which we want to be making our

decisions, but it seems more correct to say that money is power. This was expressed years later by James Hansen (see below).

The industrial disaster in Bhopal (state capital of Madhya Pradesh, India) in 1984 was another reminder how greed caused insufficient considerations for people's safety and environmental health. It was called an '*organized irresponsibility*' and took place in a Union Carbide factory making pesticides. The disaster was the logical consequence of poor plant design, lack of maintenance, and very low consideration of staff safety together with economic stress. Water had leaked into a storage tank containing 43 tons of methyl isocyanate (MIC), which started a reaction. This reaction is exothermic – the reaction rate increases with temperature – so the reaction rose quickly, and the mixture started boiling. The gas cloud, containing cyanide and the colourless poisonous gas phosgene, having a great inhalational toxicity, spread across the sleeping city, injuring more than half a million people. Estimates of the death toll range from 3700 to 16 000 people. Not only was the air deadly polluted, the groundwater outside the plant area, where large slum areas had developed, had become toxic. As a result of the disaster there was an emerging environmental justice movement, and both local and national groups were formed to campaign for legislative reform. There was great disillusion with regulators' inability to protect the environment and public health.[26]

James Hansen, director of the NASA Goddard Institute for Space Studies and a world leading scientist on climate issues, had already worked with climate change reality in the 1980s. Speaking as a NASA scientist he issued a warning that the world is failing '*miserably*' to deal with the worsening dangers. He presented what's considered the first warning to a mass audience about global warming in June 1988. At a US congressional hearing he declared '*with 99% confidence*' that a recent sharp rise in temperatures was a result of human activity. At the time I read about his warnings but did not understand the extent of the issue. More than 20 years later he expressed his frustration with greenwashing: '*politicians are happy if scientists provide information and then go away and shut up*'.[27] He also described how his testimony was misunderstood and misinterpreted. In his book Hansen expresses his experiences of climate debates:

> '*The scientific method, in one sense, is a handicap in a debate before a non-scientist audience. It works great for advancing knowledge, but to the public it can seem wishy-washy and confounding: 'on one hand this, on the other hand, that.' The difference between scientist-style and lawyer-style tends to favour the contrarian in a discussion before an audience that is not expert in the science.*'

Hansen has continued his brave battle.

On one of the last days of April 1986 my wife and I had a picnic and collected small nettles to make nettle soup. Returning home we listened to the news that the Swedish nuclear plant Forsmark had an emergency shut down because of leaking radiation. Days later it was discovered that the true source of radiation was far away, the Chornobyl nuclear reactor. Prevailing winds brought the nuclear fallout from Ukraine to Sweden and infected vegetables,

such as nettles, with caesium 137. We ate our soup before we became aware of the radiation damage.

Nuclear energy accidents are rated from 1 to 7 on the International Nuclear Event Scale. There are only two nuclear disasters rated 7, Chornobyl and the 2011 Fukushima Daiichi nuclear disaster in Japan. Naturally, the nuclear accidents have influenced not only the opinion about nuclear energy but also investments in new plants. Nuclear energy has been presented as an energy source without a carbon footprint, but as the climate crisis has become apparent for the general public, the resistance to nuclear power has also increased.[28] By 2022, however, there are great movements to make nuclear power attractive again.

In 1987 I got a full professorship in Industrial Automation at Lund University and the research at the Department of Industrial Electrical Engineering and Automation forced me – and inspired me – to address automation problems in water systems as well as in electrical power systems. I started to appreciate that there are significant couplings between the disciplines, but it took me several years to get a deeper understanding of the interactions. In a way, this reflects the academic research problem. In order to attract financial support, one has to be highly specialized and use the right buzzwords. Furthermore, to explore couplings between research areas is a significant effort, and therefore one must work with the problems for a long time before a solid basis for the research can be formed.

In 1988 the UN Environment Programme (UNEP) and the World Meteorological Organization (WMO) established IPCC, the Intergovernmental Panel on Climate Change. This was endorsed by the UN General Assembly in the same year. The first IPCC Assessment Report was published in 1990 and formed the background information for the UN Framework Convention on Climate Change (UNFCCC) and the Rio conference in 1992.

By 1989 the CO_2 concentration in the atmosphere had reached 350 ppm. In November 1989, Margaret Thatcher, for the last time in her official capacity as the British Prime Minister, presented a speech to the UN General Assembly on environment and climate change.[29] Considering that Mrs Thatcher had a background in chemical research, she had a deep understanding of the problems we faced and presented ways to resolve them: '*The result is that change in future is likely to be more fundamental and more widespread than anything we have known hitherto. …. It is no good squabbling over who is responsible or who should pay. We shall only succeed in dealing with the problems through a vast international, co-operative effort.*' This was extraordinarily prophetic, and her words were even more shocking from the lips of a right-wing world leader who couldn't be dismissed as an irritable hippy. If the world had heeded her warning back then, imagine where we would be now? However, only weeks after her speech the Berlin wall fell, and the world got other priorities.

1990 global population: 5.3 billion.
Global CO_2 concentration: $\cong 280 + 74 = 354$ ppm

In June 1992 the UN Conference on Environment and Development (UNCED) took place in Rio de Janeiro, Brazil, and became known as the Earth Summit.[30] It was organized 20 years after the first Human Environment Conference in Stockholm, Sweden. High representatives from 179 countries were gathered in a massive effort to focus on the impact of human socio-economic activities on the environment. The interdependence of social, economic, and environmental factors was recognized, even if the term 'nexus' was invented only decades later. Success in one sector requires action in other sectors, so a systemic view is not a new invention. Integrating and balancing economic, social, and environmental concerns in meeting our needs is vital for sustaining life on Earth. This would require new ways of production, consumption, lifestyle, and decision making. The UNCED conference produced Agenda 21, an almost revolutionary programme how to invest in a sustainable future.[31] The principles formulated in the Rio Declaration are still valid. The Rio conference also decided to form the UN Framework Convention on Climate Change (UNFCCC). The report[32] states early that '*Acknowledging that change in the Earth's climate and its adverse effects are a common concern of humankind*.' Furthermore, the call for global cooperation is not new: '*Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions*.'

Speaking to the British newspaper *The Guardian* in 2018, James Hansen said: '*All we've done is agree there's a problem. We agreed that in Rio in 1992 and re-agreed it again in Paris in 2015. We haven't acknowledged what is required to solve it. Promises like Paris don't mean much; it's wishful thinking. It's a hoax that governments have played on us since the 1990s*'.[33] Dr Hansen gave a lecture a few years ago and asked the audience: '*What would you do if you know what I know?*' Behind him on the screen he showed pictures when he was arrested by the police during a climate demonstration outside the White House. Can a researcher balance scientific integrity with political engagement? *Yes, I think it is necessary*. As the author Roger Pielke discusses in his book *The Honest Broker*[34] the researcher should have a role of 'honest broker', to clarify pros and cons of different actions instead of only present specific solutions.

A truly scientific debate should not be mixed up with political conflicts as I had experienced in the nuclear energy debate in the 1980s. Behind every diagram, table, or line of text, there are not only many hours of work. There is also a human being: we are parents, grandparents, friends, family members, or citizens. As a researcher I am also obliged to be a human. On this finite planet, we need to change the way we think, particularly about where and how we live, work, and travel, along with what and how much we consume. We have unmistakable indications that now is the time to make a change. Each one of us can play an important role in creating a world where we all live within our ecological limits. Even small actions can make a big difference.

James Hansen dedicated his book about the approaching climate crisis[35] to his grandchildren. A dominating driving force for me is my responsibility

for my own grandchildren. *'Did you try to make a better world?'* Will we be considered good ancestors?

In the late 1990s my wife and I visited Morocco for a short holiday during the dark Swedish winter season. Instead of staying on the beach we wanted to discover more of the interesting country. We had heard about the Blue People, nomads from the Sahel region, so we went to Guelmim (Gulimin), found a local guide at the street, and continued to an oasis at the edge of the Sahara Desert. The Blue People had arrived on camels from far away and stayed in the oasis to trade goods they needed. A little pond of brown water in the oasis, around 10 metres across, provided the difference between life and death. We were invited into the tent of a proud representative of the people. This was one of the great memorable moments in my life. We had tea together and talked via our interpreter for hours. One of the first questions from our host was: 'Do you have water at home?' 'Yes', we replied. 'Do you have sufficient water for your cattle?' he continued. Thinking about the wealth of water in Sweden and our clean beautiful lake close to our little summer cottage I did not know how to answer the question properly, but said: 'Yes, the cattle have enough water'. I did not dare to mention that our lake has drinkable water. His immediate reply was: 'Why then did you come here?' His question has stayed with me since then: how would you properly answer his question and not feel guilty? Having clean water available is a sign of extravagant wealth. Too often we take it for granted.

Mining operations have a far higher cost than what is included in the price of the extracted mineral. Too often somebody else has to pay for disasters and for the clean-up of soil or polluted waters. All over the world there are abandoned mining sites causing severe environmental damage and human suffering.

In 1998 a mining accident took place at a mine located in Los Frailes, Andalusia, in southern Spain. The Swedish company Boliden was involved, since the mine was owned by Boliden's subsidiary, Boliden Apirsa S.L. A dam at Apirsa's mine breached, resulting in the release of 4–5 million m^3 of acidic metal-bearing water and tailings sand along the river Guadimar. The accident impacted large areas of agricultural land and affected areas 40 km downstream from the mining area. The clean-up operation took 3 years, at an estimated cost of €240 million.[36]

2000 global population = 6.1 billion.
Global CO_2 concentration: $\cong 280 + 89 = 369$ ppm

In the year 2000 we were made aware about still another accident – this time in Romania. The Baia Mare gold mine, operated by a joint Australian-Romanian venture, had spilled more than 130 000 m^3 of cyanide in four rivers, among them the Danube. It affected not only aquatic and plant life for long sections of the rivers but also drinking water sources for people in Serbia, Hungary, Romania, and Bulgaria for many months. Efforts from EU to ban the use of cyanide in mining have been blocked or ignored.[37]

In 2000 the UN Millennium Development Goals, time-bound and measurable goals for combating poverty, hunger, disease, illiteracy, environmental degradation, and discrimination against women, were presented. The goals were to be achieved by 2015. We realized that we had made a lot of improvements, but not enough, during the first 15 years of the new millennium.

I had worked with the water–energy nexus for a few years when the 17 UN Sustainable Development Goals (SDGs) were adopted by the international community in 2015 as part of the 2030 agenda for sustainable development. There are a lot of interlinkages between the various SDGs. Therefore, it is important to adopt an integrated approach towards their implementation, to serve not only as visions but also as guides. Sufficient energy and water will be needed to meet nearly all the development goals. SDG6 – clean water and sanitation – depends a lot on the availability of renewable energy, recognizing that much conventional energy generation today depends on the availability of water. SDG7 – access to affordable, reliable, sustainable, and modern energy for all – depends strongly on the development of renewables like solar photovoltaic and wind. Access to clean water and clean energy are closely coupled to the development of human health and well-being, environmental health and security.[38] How do we measure the success of the SDG?

During 2005–2010 I served as the editor-in-chief for three IWA journals, *Water Science and Technology*, *Water Supply,* and *Water Practice and Technology*. The contents of the journals reflect contributions from many of the 50 IWA specialist groups. It gave me the opportunity to get a basic appreciation of other specialist areas than my own research area of instrumentation, control and automation. This position helped me to further appreciate many couplings between various water aspects and energy, biodiversity, climate, and food.

Studying climate systems, I soon got to learn about three prominent Swedes who contributed significantly to the advancement of climate science: Svante Arrhenius, Bert Bolin, and Carl-Gustaf Rossby.

While studying physical chemistry in the 1960s, I did not realize Arrhenius' role in climate research, only that he had described how chemical reaction rates depend on temperature. In 1889 Arrhenius suggested a physical interpretation of this phenomenon which is now known as the Arrhenius equations. Arrhenius was professor in *physics* in Stockholm 1885–1905, and university rector (vice chancellor) 1897–1902. He became the first Swedish Nobel Prize winner when he was awarded the Nobel Prize in *chemistry* in 1903. Actually, Svante Arrhenius is considered the founder of physical chemistry together with Wilhelm Ostwald and Jacobus Henricus van't Hoff.

In 1896 Arrhenius published his ground-breaking paper 'On the influence of carbonic acid in the air upon the temperature on ground'.[39] He was the first scientist to model the greenhouse effect, that is how CO_2 will increase the heat content on earth. His calculations of the relationship between greenhouse gas concentration and temperature increase were amazingly close to the calculations made by the IPCC a century later. He estimated that if the CO_2 content in the atmosphere were to be doubled then the temperature would increase 5–6°C.

Professor Bert Bolin (1925–2007), a Swedish meteorologist, was another climate pioneer. He was one of the founders of IPCC and became its first chairperson in 1988–1998. Bolin was heavily involved in various international groups concerned with climate change in the 1960s. He was also the scientific director of the European Space Agency (ESA). He recognized that the emission of CO_2 was a key problem. Bolin organized several national and international conferences in Sweden in the 1970s and served as an advisor to Swedish governments and prime ministers, for example to Prime Minister Olof Palme in the 1970s and 1980s. Thanks to Bolin, Sweden became an important partner in climate work and Bolin's efforts have probably influenced Swedish energy policy. Bolin described many of his experiences in his own book.[40]

Carl-Gustaf Rossby (1898–1957) was a Swedish-American meteorologist and made significant scientific contributions in meteorology. He developed mathematical models describing large-scale air movement. In 1928 he was appointed professor at MIT, the first US professor in meteorology. He identified sinusoidal waves in the polar jet stream, now known as Rossby Waves. They can explain how global warming can cause extreme cold weather in the winter in the southern parts of the USA or in Europe. He worked on mathematical models for weather forecasting, the Rossby equations, forecasting the weather using an electronic computer in 1950. In 1950 he returned to Sweden and founded the Institute of Meteorology in connection with the University of Stockholm. He appeared on the cover of *Time* magazine in 1956.

I retired from my academic responsibilities in early 2006 and this opened new possibilities to think and study independently of financial support and peripheral academic duties. My primary goal was to further explore how water and energy are related. In my research I had worked in parallel with control and automation issues in water systems and in energy systems, but in separate silos. To some extent this is caused by the financing structures that have encouraged specialization rather than multidisciplinary cooperation. I realized that water professionals easily understood the importance of energy for all kinds of water operations. Energy people, however, most often took water availability for granted. Among my contacts, water scarcity was not an issue and therefore this was considered a non-issue.

Within a few years after 2006 there was an increasing interest in the water–energy nexus. The interest among water professionals had been there for some years, but many energy operators and energy professionals now considered the water–energy nexus crucial. A landmark report by Sandia Labs in 2006[41] inspired my own research.

In 2008 I visited Allan R. Hoffman in Washington DC. He is a solid-state scientist turning into a renewable energy and a water–energy professional, and served for many years as Senior Analyst, US Department of Energy, Washington DC. He had played a substantial role in the development of renewable energy while being a top scientific advisor in Washington. Allan had opened my eyes to the issue of water–energy nexus and inspired me in writing my first book on water and energy.[42] Since then, Allan and I have had regular contact and I have learnt a lot from him. In his book on *The US Government and Renewable*

Energy,[43] he describes how renewable energy was already an issue at the top political level in the late 1970s. Allan was instrumental in the effort to make President Carter decide to support renewable energy by adding a solar hot water heating system to the White House roof in 1979. The Reagan Administration had other priorities and would favour nuclear energy and fossil fuels. The solar panels were removed from the White House roof. The renewable energy R&D budget got reduced by a factor of eight from its height at the end of the Carter Administration.

A significant report on water and energy was published by the UN[44] in 2014. In the same year, water and energy was the special theme for the 2014 World Water Day in Stockholm and the US Department of Energy published a major report on the water–energy nexus.[45] I had the pleasure of being invited speaker both at the World Water Day in Stockholm and (later) the corresponding day in Oslo in 2014. The Stockholm World Water Week programme in 2014 was composed around the water and energy theme.

More than 15 years ago I met Oren Lyons, the Indian Chief from North America. We had invited him to Lund University. He made a lasting impression on me. Among other things he told me: '*If you do not have a moral question in your governing process, then you do not have a process that is going to survive*.' This is my deep motivation not only to understand the couplings between water, energy, food, lifestyle, and climate change but also to realize the impact of climate change, our living conditions, and basically the future of our children and grandchildren. Oren Lyons gave me new insights how our lifestyles influence the fate of our environment and our limited resources.

2010 global population = 7.0 billion
Global CO_2 concentration: $\cong 280 + 110 = 390$ ppm

Working in academic research with colleagues and students I have had the privilege to visit many countries around the world and live an 'everyday life'. In this way I have got some first-hand impressions of environmental problems. I have had problems breathing due to air pollution in Beijing, worried about water scarcity in northern China, watched how the long drought in Cape Town made the day zero real, felt the drought problems in Queensland, Australia followed by flooding, been confused how the monsoon in Malaysia was delayed, and with great frustration and anger learnt how inhabitants in the Niger Delta in Nigeria suffered from oil leakages and flaring. Still, being a visitor, I was not a victim.

The Deepwater Horizon oil spill in 2010 got huge attention, an event being closely monitored by powerful media. Around 780 000 m^3 of oil leaked out into the ocean, a spill that was three times the amount of oil leaking from the Amoco Cadiz disaster in 1978. The long-term oil leakages in the Niger Delta in Nigeria surpasses all these disasters having spilled out 2–3 times as much as the Deepwater Horizon. The Mexican Gulf and the Nigerian disasters have been described in detail elsewhere.[46]

The summer of 2018 was a wake-up call for many Swedes. In most of the southern half of Sweden it was the warmest summer on record. We experienced destructive forest fires all over the country. Climate change suddenly was no longer abstract: it became real and threatening.

If I had predicted in the summer of 2018 that in half a year, there would be a massive movement among young people to take climate change seriously and wake up the older generations, then only few would have believed me. And even more remarkable: this movement was inspired by a 15-year-old girl Greta Thunberg with pigtails, having Asperger syndrome, striking alone outside the Parliament building in Stockholm. Her demands were that the Swedish government reduce carbon emissions as stipulated in the Paris Agreement 2015. Unlike other climate demonstrators, Greta protested by sitting outside the Riksdag (Parliament) every day during school hours with the signboard *Skolstrejk för Klimatet* (school strike for the climate). Later in 2018 she would be speaking at the World Economic Forum, meeting the Pope, and meeting EU leaders. *Time* magazine named her as one of the world's 25 most influential teenagers of 2018. In 2019 *Time* magazine named her The Person of the Year. Today, in 2021 Greta has become an icon and role model for many young people that worry about the climate, notably at the COP26 meeting in Glasgow. Even Prime Minister Boris Johnson cited her in his introductory speech at COP26. *Her straight-forward message has consistently been: 'You have to listen to the scientists and take action.'*

2020 global population = 7.8 billion.
Global CO_2 concentration: $\cong 280 + 132 = 412$ ppm

We have a vivid memory of the August 2020 Beirut explosions. Ammonium nitrate, used predominantly in agriculture as a high-nitrogen fertilizer, was stored in the Port of Beirut. The massive explosion damaged buildings throughout the city and killed almost 200 people and injured more than 6500. The economic consequences for Lebanon are catastrophic. Such an accident could have been avoided without so much corruption and greed.

The UN General Assembly met on 21 September, 2021, and the Secretary General António Guterres presented a remarkable and razor-sharp speech to the world leaders.[47] From the complete talk I have chosen some sentences, illustrating his serious message:

> *'I am here to sound the alarm: The world must wake up. We are on the edge of an abyss – and moving in the wrong direction. Our world has never been more threatened. Or more divided. ….. The climate crisis is pummeling the planet. …. Human rights are under fire. ….Science is under assault. …. Solidarity is missing in action – just when we need it most. … we are getting an F in Ethics. …. The recent report of the Intergovernmental Panel on Climate Change was a code red for humanity. We see the warning signs in every continent and region. … We need a*

45 per cent cut in emissions by 2030. Yet a recent UN report made clear that with present national climate commitments, emissions will go up by 16% by 2030. …. We are weeks away from the UN Climate Conference in Glasgow, but seemingly light years away from reaching our targets. We must get serious. And we must act fast. …. Like never before, core values are in the crosshairs. A breakdown in trust is leading to a breakdown in values. Promises, after all, are worthless if people do not see results in their daily lives. …. The problems we have created are problems we can solve.'

Surely, there are some positive technology developments. The efficiencies of a lot of equipment and industrial processes are improving all the time. Membrane technology has made tremendous improvement, influencing water treatment technology, including desalination. The costs of wind and solar photo-voltaic power are decreasing at an impressive speed, while the price for fossil fuel can only go upwards in the future, despite occasional price drops. Still, according to the International Energy Agency's (IEA) World Energy Outlook 2021[48] the rate of change to meet the climate crisis is far too inadequate.