Proklima

green cooling initiative

Green Cooling Technologies

Market trends in selected refrigeration and air conditioning subsectors

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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The Green Cooling Initiative

Refrigeration and air conditioning are responsible for a significant share of global greenhouse gas emissions. Especially in developing and emerging countries, the demand for cooling equipment is rising. Low efficiencies and high leakage rates of refrigerant gases with high global warming potential will increase these emissions drastically. Our goal is to accelerate the transfer of environmentally friendly technologies in the refrigeration and air conditioning sectors to and within developing countries. We believe that the exchange between technology suppliers and users, as well as between the industry, public institutions and civil society is crucial for the promotion of green cooling technologies. We want to provide useful information, give access to knowledge and get you connected with others working on the same goal: Promoting green cooling technologies worldwide.

The International Climate Initiative

Since 2008, the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has been financing climate and biodiversity projects in developing and newly industrialising countries, as well as in countries in transition. Based on a decision taken by the German parliament (Bundestag), a sum of at least 120 million euros is available for use by the initiative annually. For the first few years the IKI was financed through the auctioning of emission allowances, but it is now funded from the budget of the BMUB. The IKI is a key element of Germany's climate financing and the funding commitments in the framework of the Convention on Biological Diversity. The Initiative places clear emphasis on climate change mitigation, adaption to the impacts of climate change and the protection of biological diversity. These efforts provide various co-benefits, particularly the improvement of living conditions in partner countries.
The IKI focuses on four areas: mitigating greenhouse gas emissions, adapting to the impacts of climate change, conserving natural carbon sinks with a focus on reducing emissions from deforestation and forest degradation (REDD+), as well as conserving biological diversity.
New projects are primarily selected through a two-stage procedure that takes place once a year. Priority is given to activities that support creating an international climate protection architecture, to transparency, and to innovative and transferable solutions that have an impact beyond the individual project. The IKI cooperates closely with partner countries and supports consensus building for a comprehensive international climate agreement and the implementation of the Convention on Biological Diversity. Moreover, it is the goal of the IKI to create as many synergies as possible between climate protection and biodiversity conservation.

GIZ Proklima

Proklima is a programme of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Since 2008 Proklima has been working successfully on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) under its International Climate Initiative (ICI) to disseminate ozone-and climate-friendly technologies.
Proklima has been providing technical and financial support for developing countries since 1996, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) to implement the provisions of the Montreal Protocol on Substances that Deplete the Ozone Layer.

Contents

Executive Summary

The study analyses the potential of green technologies in the refrigeration and air conditioning (RAC) sectors. It provides an overview on the global cooling value chain for key RAC subsectors and how private and public stakeholders as well as the civil society can drive dynamics towards a wider penetration of green cooling technologies.

The refrigeration and air conditioning sectors are responsible for about 15% of global greenhouse gas (GHG) emissions, equivalent to 4.8 GT CO_2 per annum (2012) going up to 12 GT CO_2 (2030). Emissions are growing at a rate which is at least three times faster than the global average increase of GHG emissions. Emissions in the RAC sectors originate from the use of high-global-warming-potential (GWP) refrigerants and energy consumption of RAC systems. About 50% of the emissions can be avoided globally by 2030 against the business-as-usual (BAU) by leapfrogging from high GWP refrigerants to low GWP natural refrigerants and applying best in class, highly energy efficient appliances.

The Technology Mechanism of the UN Framework Convention on Climate Change (UNFCCC) targets an accelerated technology transfer across all sectors and countries globally to allow the deployment of the least climate harming technologies. Front runners among the public and private sector as well as from the civil society will play a pivotal role in driving the dynamics towards low-GWP solutions. The urgency to reduce GHG emissions requires that available technologies are rapidly deployed. With the phase-out of chlorofluorocarbons (CFCs) low-GWP technologies with natural refrigerants were directly deployed for refrigerators while for mobile air conditioning (MAC) and many other appliance systems, high-GWP hydrofluorocarbons (HFC) were introduced. The engagement of the civil society and NGOs was driving the leapfrogging to the best technology for domestic refrigerators. Public, regulatory pressure in the EU is now driving the dynamics also for MAC systems, and the German car industry is now opting to use natural refrigerants. The study identifies key factors through which different public, private and civil society stakeholders can influence the dynamics towards an accelerated and wider penetration of green cooling technologies.

To allow a better assessment on how stakeholders can steer towards green cooling technologies, this study provides insights into the global cooling value chain for the three key RAC subsectors, unitary air conditioners, chillers and mobile air conditioning.

Unitary Air Conditioning (UAC) is the most significant RAC subsector, both in terms of current and future sales and carbon emissions. With some 100 million units sold (2012), the UAC subsector is the single largest RAC subsector with a market size of USD 60 billion. Nearly two thirds of the world demand originates in Asia with China being responsible for the main share of 38%. Future demand for UAC is expected to nearly triple by 2030 to over 1.7 billion units. The production of UAC is also highly concentrated in China. China accounts for 65% of the global production capacity of UACs. The next biggest producer is Thailand with a 7% share of the global production capacity. Approximately three quarters of the total production in China are dominated by the five leading players (Gree, Midea, Haier, Chigo, Hisense).

UAC green cooling potential: Applying best available technologies currently in the market with high energy efficiencies and natural refrigerants can lead to lifetime CO_2 emissions reductions for UAC systems from approximately 25 to 10 tCO_2eq. The natural refrigerant HC-290 has been tested successfully by leading manufacturers in China and India and is now available in the market. Countries such as Japan and Korea but also China have been running labelling and minimum energy efficiency programs over years and were able to significantly increase the energy efficiencies of the UAC stock. From 2006 to 2012 China has improved the Energy

Efficiency Ratio (EER) of the best UAC models available in its market from 4 to 6. Most of the units sold in developing countries still have an EER lower than 3, significantly below the best available standards.
UAC green cooling dynamics: The leading manufacturers for UACs, in particular the leading Chinese manufacturers are now able to sell highly energy efficient UACs with inverter technologies and natural refrigerants. Governments and end users for all countries will benefit from the introduction of mandatory labelling, the introduction of demanding minimum energy efficiency standards and front-runner programs. Labels are ideally linked to the mandatory use of natural refrigerants.

Mobile Air Conditioners (MACs): Over 90% of cars are now equipped with MACs. In total some 56 million units are sold with a value of about 6 billion USD. Demand in Asia has grown very strongly during the last decade with Asia now accounting for nearly 50% of the global demand. The remainder of the market is mostly split between the US and Europe. MAC producers traditionally were producing for their regional original equipment manufacturers (OEM), i.e. the leading Japanese MAC manufacturers Denso, Calsonic Kansei and Keihin-Sanden for Toyota, Nissan and Honda, the leading European MAC producers, Behr and Valeo, for Daimler, VW, BMW, Renault and PSA, the leading US MAC manufacturers Delphi and Hallo-Visteon for General Motors and Ford. With the emergence of the Chinese car market as the largest market of the world, European, Japanese, US and Korean manufacturers were setting up joint ventures with Chinese car manufacturers. Also the traditional MAC suppliers moved to China to set up local production facilities. Now the leading production locations for MAC systems are China, Japan, the US and Germany.
MAC green cooling potential: Applying best available technologies currently in the market with high energy efficiencies and natural refrigerants can lead to life time CO_2 emissions reductions for UAC systems from around 25 to 10 t CO_2eq. Coefficients of Performance (COP) for MAC systems continuously improved during the last ten years from 1 to up to 4.
MAC green cooling dynamics: It will be interesting to see if other regions will follow Europe in the move towards low-GWP refrigerants in the MAC subsector. China will likely play a decisive factor in this regard being the leading market place for car and MAC manufacturing. Most European players present in China are likely seeking synergies with their technological developments in Europe. Globally, there is significant emission reduction potential with labelling for energy efficiency and Minimum Energy Efficiency Standards (MEPS) for MAC systems.

Chillers: Nearly half of the demand of the 7.4 billion USD market for chillers is coming from Asia where China has a 38% market share. The next biggest market is the US market. Total global sales are some 350.000 units (2012). The production of chillers is less concentrated than for UAC and MAC. Leading producing countries are China, the US and Italy. The international market is still dominated by three US (Carrier, Trane, York) and two Japanese brands (Hitachi and Daikin) although Chinese brands (Gree, Haier, Midea, Broad) are rapidly gaining market share mainly in Southeast Asia and the Middle East.
Chiller green cooling potential: Applying best available technologies currently in the market with high energy efficiencies and natural refrigerants can lead to lifetime CO_2 emissions reductions for UAC systems from approximately 3500 to 1500 t CO_2eq. Significant emission reductions can be achieved by moving towards better energy efficiency with EER above 5, where most chillers deployed in developing countries still have EER below 3 or 4.
Chiller green cooling dynamics: Nearly all leading manufacturers globally offer highly energy efficient chillers with natural refrigerants. The deployment of natural refrigerants for chillers is still held back through standards or regulations limiting their use, especially regarding hydrocarbons due to their flammability. These barriers need to be removed. Both, front-running private industry players and the public can play a key role in this respect. Often energy efficient chillers with natural refrigerants have somewhat higher upfront costs but lower operation costs. This barrier between higher upfront and lower running costs can be effectively addressed through available loan financing. The

public in cooperation with private financial institutions can play a key role in providing the required financing and guarantees especially for small and medium enterprises and operators. The public would greatly benefit by also applying Minimum Energy Efficiency Standards (MEPS) for chillers in combination with labelling and certifications requiring the use of natural refrigerants.

1 Introduction

1.1 The Challenge

The worldwide demand for refrigeration and air-conditioning (RAC) is increasing steadily due to a growing population, urbanisation and economic growth. More and more people are able to afford domestic refrigeration and air-conditioning and the same is true for enterprises. A functioning cold chain can prevent food going to waste. Cooling is often necessary for the development of competitive industry and services. The energy demand for cooling in developing countries[1] is likely to rise by 7% annually until the year 2050 (IEA, 2010).

Calculations by GIZ Proklima have shown that equipment with low efficiencies and high release rate of refrigerants with high global warming potential (GWP) are the reasons why the RAC sectors are responsible for 10 to 15 % of global greenhouse gas emissions. This is the equivalent of 4.8 Gt CO_2eq per year, but this number is rising continuously and is estimated to reach more than 12 Gt CO_2eq per year by 2030 (GIZ Proklima, 2012, based on Schwarz et al., 2011).

On average, about two-thirds of greenhouse gas (GHG) emissions are caused by energy consumption (indirect emissions) and one-third by the use of refrigerants (direct emissions) (GIZ Proklima, 2012). Direct emissions can be completely avoided by switching to natural refrigerants with a negligible or no GWP and it is estimated that more than 50% of indirect emissions from energy consumption can be cut by improving product efficiency (GIZ Proklima, 2012).

Increasing demand for electricity due to refrigeration and air conditioning can contribute to the already strained energy supply in many developing countries. This now rising demand often comes after long periods where little money was invested to expand the electricity production, leading to problems with energy security (UNIDO, 2008; CLASP, 2002; WEC, 2013). Black-outs are not only an inconvenience but have negative impacts on the whole economy.

Whilst energy efficiency in industrialised countries is often discussed in the context of environmental impacts, in developing countries it helps to meet additional goals: The same electricity generation can be used to supply more people in countries where electrification rates are still low (WEC, 2013). It also reduces the need for additional investments in energy infrastructure, which can be a huge financial burden to poor countries (WEC, 2013). Energy efficient appliances often lead to net savings for households because of lowered energy bills. Compared to industrialised countries, the cost of electricity per kWh relative to income is typically much higher in developing countries. Thus the investment in energy efficient equipment yields a greater economic benefit.

Scope of this study and guiding questions

The aim of this study is to analyse the potential of green technologies in the refrigeration and air conditioning (RAC) sectors and show the key actors and drivers promoting their dissemination. The study compiles information about the market structure, key technology options and important stakeholders in order to answer the following questions:

[1] This study refers to developing and developed countries where the designations “developed” and “developing” do not necessarily imply a judgment on the state of the development process in a certain country. The designations avoid having to differentiate between the slightly differing classifications under the Montreal Protocol and the UN Framework Convention on Climate Change (UNFCCC) unless necessary for clarification and are, therefore, used for easier comprehension.

- What are the key RAC subsectors with a high potential for technology transfer that leads to significant CO_2 emission reductions?
- What is the global demand for refrigeration and air conditioning now and in the future?
- Which countries and companies play key roles in the supply and purchasing of RAC equipment?
- What are the key technology options and technology trends for specific RAC subsectors?
- What does the stakeholder landscape look like? What are the dynamics of green cooling technologies spreading in the different subsectors? What are the contributions and potential contributions of governments, NGOs and private sector stakeholders to sector transformation?
- What are significant international and national regulations and standards in the RAC sectors?

The three subsectors unitary air conditioning (UAC), air conditioning chillers and mobile air conditioners (MAC) were chosen because of their high GHG emission reduction potential and their high potential for applying natural refrigerants instead of fluorinated gases. The percentage of cars, houses, offices and other buildings with air conditioning is growing, especially in developing countries. UAC, air conditioning chillers and MAC are among the most significant contributors to GHG emissions of all RAC sectors and therefore among the ones with the highest emissions mitigation potential. UACs and MAC are significant mainly because of the high number of individual units whereas AC chillers can individually contain substantial amounts of refrigerant. High leakage rates and poor end-of-life refrigerant recovery make MAC a subsector with a high potential for emission reductions. There are natural refrigerant solutions for applications in all of these subsectors already in use. Information for this study was collected in a thorough literature review and a model was used to calculate current and future stock numbers and emissions.

The study addresses active and potential members in the Green Cooling Initiative (GCI) network and related technology partnerships who want to get involved in green cooling technologies. This includes private, public and civil society actors in developing and industrialised countries with the ability to develop, market or support the dissemination of such green technologies in the RAC sectors.

1.2 Environmental impact of the RAC sectors

Refrigerants pose a threat to the environment because of their ozone depletion potential (ODP) and GWP. They fall into the following groups:

Table 1: Different groups of refrigerants and their ozone depletion and global warming potentials compared to CO_2 on a 100 (GWP_{100}) and 20 (GWP_{100}) year time horizon (IPCC, 2007)

Substance group	Abbreviation	**ODP**	**GWP_{100}**	**GWP_{20}**	**Atmospheric lifetime**	**Example** (refrigerant/foam blowing agent)
Saturated chloro-fluorocarbons	CFC	0,6-1	4750-14,400	6,730-14,400	45-1,700	R11, R12
Saturated hydrochloro-fluorocarbons	HCFC	0,02-0,11	77-2310	273-5,490	1.3-17.9	R22, R141b
average			*1,502*	*4,299*	*11.4*	
Saturated hydro-fluorocarbons	HFC	-	124-14,800	437-12,000	1.4-270	R32, R134a
average			*2,362*	*4,582*	*21.7*	

Unsaturated hydro-chlorofluorcarbons	u-HCFC	<0.001	0-10		R1233zd
Unsaturated hydro-fluorocarbons	u-HFC	-	<1-12	days	R1234yf, R1234ze, R1234yz
Natural refrigerants		-	0-20		R744 (carbon dioxide) R717 (ammonia) R290 (propane)

The GWP of a substance can be determined for different time horizons (usually 20, 100 or 500 years). Because of the different atmospheric lifetimes ranging from a few years to several centuries, usually the GWP_{100} is used. HFCs with an average lifetime of 21.7 years might be better represented by the GWP_{20}.

The Montreal Protocol on substances that deplete the ozone layer from 1989 is now effectively controlling the use of the ozone depleting refrigerants chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC). There has been a worldwide ban on CFCs since 2010. HCFCs, initially used as substitutes for CFCs, have been forbidden in most non-Article 5 (“developed”) countries since 2010 but are still widely used in Article 5 (“developing”) countries where they must be phased out by 2030[2].

Figure 1 shows the expected phase-out of CFCs and HCFCs in developing and developed countries.

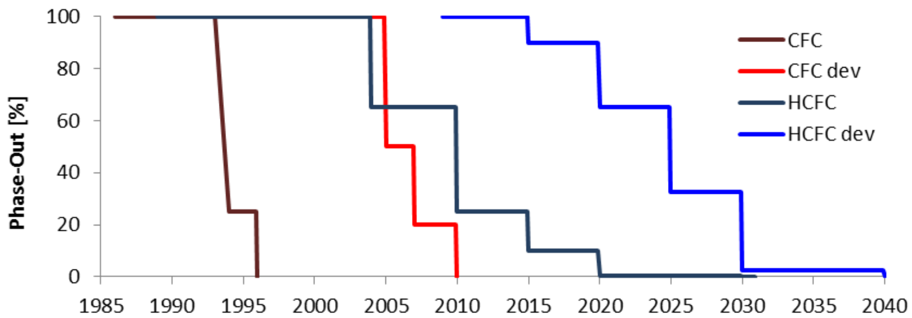


Figure 1: Phase-out plan for CFCs and HCFCs according to the Montreal Protocol

Hydrofluorocarbons (HFC) have no ozone depleting potential and are currently not controlled under the Montreal Protocol. HFCs can have extremely high GWP. They are listed under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) from 2005 as substances whose emissions are to be limited or reduced. Some countries and regions, such as the EU, have already introduced laws restricting the use of HFCs (see Chapter 3).

Unsaturated HFCs (u-HFCs, also marketed as hydrofluoroolefins, or “HFOs”) are synthetically made HFCs with no ODP and low GWP that have been developed specifically to fulfil regulations that prohibit HFCs with higher GWP (e.g., above 150). Some are slightly flammable and combustion can form hydrogen fluoride (HF). In the atmosphere their decomposition leads to formation of trifluoroacetic acid (TFA), which is a strong acid with toxicity to some organisms (Key et al., 1997). TFA exists naturally in the oceans in very low concentrations, it is highly persistent and there is no known degradation mechanism (Luecken et al., 2010). There are no studies about the longterm effect on organisms and the food chain. Whilst only 10-20% of HFC-134a are transformed into TFA, 100% of u-HFC-1234yf reacts to TFA. Studies modelling future TFA concentrations in rainwater due to u-HFC1234yf predict concentrations

[2] A residual consumption of HCFCs will be allowed until 2040.

that were already reached in extreme events in the 1990, when HFC-134a was first used more widely (Henne et al., 2010; Luecken et al., 2010; Christoph, 2002) and are regularly reached in China today (Wang et al., 2014). These models therefore seem to underestimate future TFA concentrations. Concentrations are expected to be especially high in dry regions with little precipitation or close to industrial centres and high population density. TFA has been shown to accumulate in conifers already (Christoph, 2002). TFA from Europe is expected to precipitate in Asia and Africa in concentrations of up to 2500 ng L^{-1} (Henne et al., 2010). To a small amount, TFA produces tropospheric ozone (Luecken et al., 2010).

The strong advantages of natural refrigerants are that they have zero ODP, a negligible GWP, are part of the natural biogeochemical cycles and do not form persistent substances in the atmosphere, water or biosphere. They include carbon dioxide (CO_2), ammonia (NH_3) and hydrocarbons such as propane (C_3H_8), propene (C_3H_6) and isobutane (C_4H_{12}) and have been used as refrigerants for over 150 years (Calm, 2008). Natural refrigerants are widely used in some RAC applications, for example isobutane in domestic refrigerators and ammonia in large cooling processes. Hydrocarbons (HCs) are flammable and ammonia is slightly flammable, corrosive and of higher toxicity. Therefore they require additional safety measures (

Table 2 gives a summary of refrigerant safety groups). Simple measures such as using appropriate materials, selection of safe components and technician training can handle these undesirable characteristics. Natural refrigerants are relatively cheap because they are mass produced for a wide range of uses and are readily available if distribution structures are present. Natural refrigerants can often be sourced as by-products from other processes. Recycling or disposal after use in RAC systems is easier than with CFCs, HCFCs and HFCs.

Table 2: Refrigerant safety groups after ISO817:2009 and EN378-1:2008.

	Lower toxicity	Higher toxicity
No flame propagation	A1, e.g.: R-744 (CO_2), CFC-11, R404a, HFC-134a, R410a	B1, e.g.: HCFC-123
Lower flammability	A2, e.g.: u-HFC-1234yf, HFC-152	B2, e.g.: Methyl formate, R717 (ammonia)
Higher flammability	A3, e.g.: hydrocarbons, R430a, R510a	B3

The following list shows a comparative summary of refrigerant properties, highlighting positive and negative properties of different refrigerants.

- The **ODP** of HCFCs is lower than that of CFCs, but still high enough to justify a complete phase-out.
- Both HCFCs and HFCs have a **high GWP**, up to several thousand times higher than that of CO_2.
- All fluorinated refrigerants produce **persistent wastes**. They are persistent in the atmosphere or in the case of the decomposition product TFA in the hydrosphere.
- Fluorinated refrigerants are also produced from fluorspar, which is a **depletable resource**. Its global reserves are estimated to be 240 million tonnes, most of which can be found in China, Mexico, Mongolia, South Africa and Namibia (USGS, 2013). European reserves are mainly depleted (CTEF, 2013). Mine production in 2012 was at 6.85 million t (USGS, 2013); making fluorspar available for another 35 years if consumption stays constant. The EU has included fluorspar in its list of the 14 most critical raw materials, defined by supply risk and economic importance (EC Enterprise and Industry, 2010). The reasons are that mining activities are limited to a few countries globally, the recycling rate is smaller than 1 % and substitution possibilities are few (EC Enterprise and Industry, 2010).

- In order to be able to **recycle or dispose** HCFCs, HFCs and u-HFCs, they have to be reclaimed from appliances with special equipment and be cleaned. Recycling is mainly possible for pure refrigerants and even more difficult for blends. Cleaned refrigerants can be used again. Refrigerants for disposal have to be rendered environmentally safe by incinerating them at high temperatures and collecting decomposition products such as hydrogen fluoride (HF) and hydrogen chloride (HCl). Dedicated recycling plants are rare in developing countries.
- Special **safety measures** have to be taken for hydrocarbons, u-HFCs (flammability) and ammonia (higher toxicity).
- Some CO_2 systems are not as **energy efficient** in warmer climates or need additional cycle adjustments to become as efficient as other systems. Generally, applications using natural refrigerants are as efficient as or more efficient than those using HFCs and HCFCs; HC and ammonia have superior thermodynamic properties with high critical temperatures and low boiling points (Mohanraj, 2009).
- The **costs** can be related to the system, which is typically higher for flammable or higher toxicity refrigerants. However, newly developed u-HFC refrigerants are significantly more expensive (estimates range from 100 US$/kg to 150 £/kg or more in Europe) than HFCs that have been in use for several years where patents have expired (approx. 6US$/kg), and also more expensive than natural refrigerants (e.g. CO_2: <1 US$/kg).
- Because there are no international property rights, natural refrigerants can be **produced or sold by any company in any country locally.** Far more patents are associated with HFCs, u-HFCs and u-HCFCs refrigerants and applications than with natural refrigerant applications. Only natural refrigerant system designs can be patented, not the refrigerants themselves.

Table 3: Refrigerant characteristics. Green shows positive and red negative properties

	HCFC	HFC	u-HFC	NH_3	CO_2	HC
Ozone depletion	🔴	🟢	🟢	🟢	🟢	🟢
High GWP	🔴	🔴	🟢	🟢	🟢	🟢
Persistent wastes	🔴	🔴	🔴	🟢	🟢	🟢
Depletable resources	🔴	🔴	🔴	🟢	🟢	🟢
Recycling/disposal	🔴	🔴	🔴	🟢	🟢	🟢
Safety issues	🟢	🟢/🔴	🔴	🔴	🟢	🔴
Energy efficiency	🟢	🟢	🟢	🟢	🟢/🔴	🟢
Costs	🟢	🟢	🔴	🔴	🔴	🟢
Local production	🔴	🔴	🔴	🟢	🟢	🟢

The reduction of indirect emissions (i.e., CO_2 emissions from electricity production or fuel consumption) is related to both the energy efficiency of RAC equipment and the carbon intensity of electricity production in a country or vehicle fuel. The carbon intensity indicates the amount of CO_2 released per unit (kWh) of electricity produced and is dependent on a country's energy mix. Because of its high energy consumption, the RAC sectors have a high potential to reduce these. Some countries have introduced sector specific regulations such as minimum energy performance rules to reduce the CO_2 emissions by increasing the efficiency.

Terms 1: Precautionary approach

The term precautionary approach refers to the principle that one should take caution before engaging in an activity that poses a threat to the environment or human health, even if this threat is not fully known or scientifically proven yet. By employing this principle, one means to anticipate and avoid damage as opposed to having to repair damage that could have been prevented.

Coined by the Montreal Protocol in 1987 and in the 1992 Rio declaration, the precautionary principle has become internationally recognised: *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*

Just like CFCs, HCFCs and HFCs, the newest generation of synthetic refrigerants, u-HFCs will again be responsible for introducing a persistent compound into the environment. Contrary to its predecessors, u-HFCs have no ODP and a low GWP. Their degradation product TFA however, has no known degradation pathway and will accumulate in water bodies, plants and soils. It is phytotoxic and its long term effects are not known yet. This is another case where the precautionary approach should take effect and a more environmentally-friendly technology be introduced.

1.3 "Green Cooling Technologies"

Equipment with both maximised energy efficiency and natural refrigerants, which is therefore minimising its environmental impact, is here termed "green cooling technologies". Green cooling technologies offer long-term solutions for almost all types of systems and appliances in the RAC sectors. The growing use of HFCs in the RAC sectors can be clearly linked to the phase-out of CFCs and HCFCs in these industries, a fact that was specifically noted by the Rio+20 declaration in 2012 and other high level political declarations, such as by the Climate and Clean Air Coalition (CCAC). In the past the phase-out of one group of refrigerants that damaged the environment has always led to the increased use of refrigerants that were only slightly less damaging. This happened in the switch from CFCs to HCFCs (though note that HCFCs were regularly used before the phase-out of CFCs as well) and on to HFCs in developed countries and is currently visible in developing countries where HFCs are replacing HCFCs, and to some extent in developed countries where u-HFCs are introduced. Switching from ozone depleting and climate harming fluorinated substances to natural refrigerants in energy-efficient systems and applications is often referred to as "leapfrogging". Within the Montreal Protocol, states have always been encouraged to choose alternatives that not only save the ozone layer but that also do not harm the climate, such as by the UN Secretary-General Ban Ki-moon, who urged "parties and industries to seize the opportunity provided by the HCFC phase-out to leapfrog HFCs wherever possible" in his 2011 Ozone Day message. A phase-down of HFCs is also discussed as an amendment to the Montreal Protocol. With growing concern on future regulations prohibiting the use of HFCs, countries as well as industries have to look for opportunities to leapfrog which will prevent them from having to phase new sets of fluorinated gases in and out again. Figure 2 visualises the leapfrogging scheme.

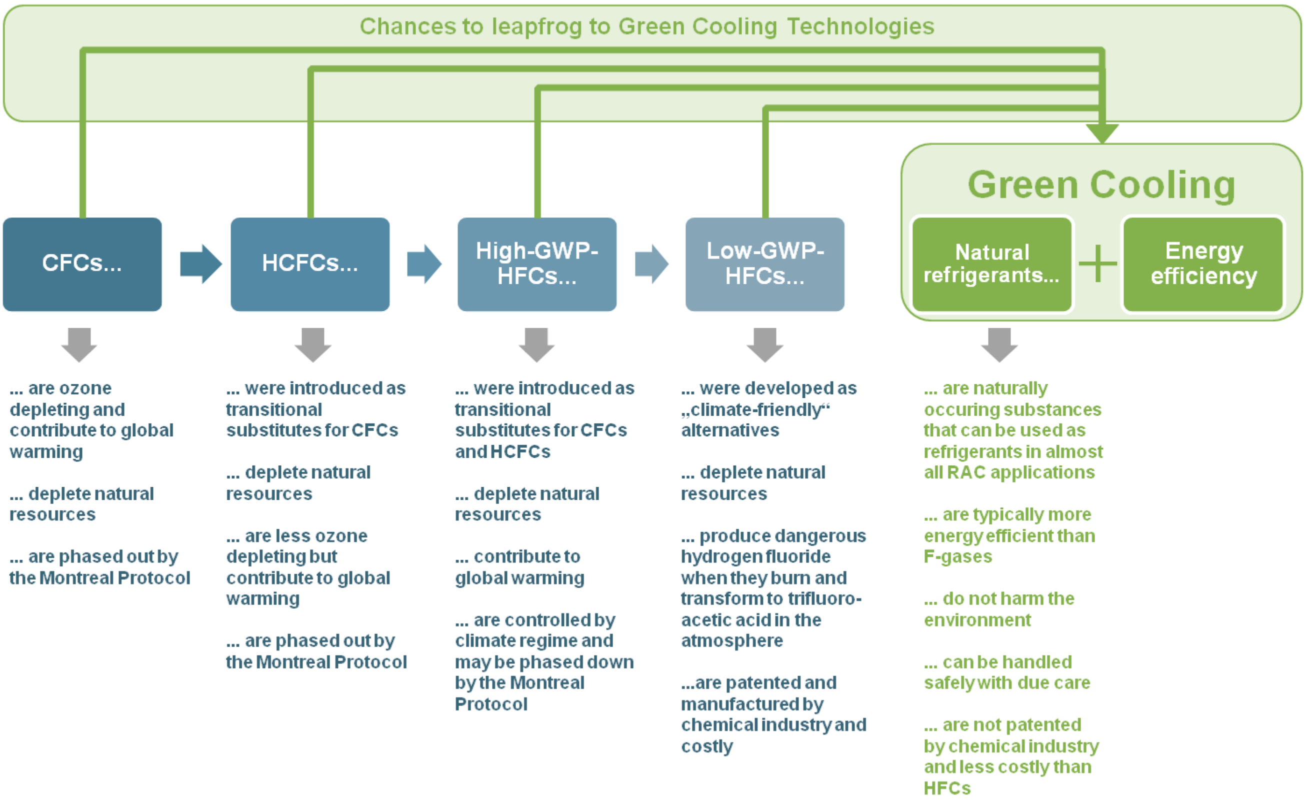


Figure 2: Leapfrogging to green cooling technologies

1.4 The Technology Mechanism (UNFCCC)

Whilst the Montreal Protocol only covers ozone depleting substances (ODS), the following substances, with a climate impact, are covered under the UNFCCC and the Kyoto Protocol: HFCs, PFCs, methane, CO_2, N_2O and SF_6. Other than the Montreal Protocol, which includes a binding prohibition of production and use of ODS, the Kyoto Protocol aims to generally limit the emissions of CO_2 and other greenhouse gases to the atmosphere. In this context it is important to take the RAC sectors into account as they have the potential to contribute significantly to the reduction of greenhouse gas emissions.

According to the Kyoto Protocol, the reduction of emissions is preferable where a high reduction can be achieved in a cost-effective way, which is often the case in developing countries where the reduction potential is high. Previous mechanisms under the UNFCCC to reduce greenhouse gas emissions include emission trading, the clean development mechanism and joint implementation. The latter two already include cooperation between developing and industrialised countries, but were criticised about being inefficient (e.g. Bullock et al., 2009; Zaman and Hughes, 2012[3]). Most importantly, the Kyoto Protocol has no overall limits on emissions or substances for developing countries where the Montreal Protocol also foresees binding targets for developing countries.

Whilst the Bali Roadmap (2007) called for emission reductions in both developing as well as industrialised countries, it was acknowledged that industrialised countries would support developing countries with less financial means. The promotion of environmentally friendly technologies was suggested as another way to reduce emissions cost-effectively with the additional benefit of economic growth and technical development.

[3] see also http://www.theguardian.com/environment/2008/may/26/climatechange.greenpolitics

In 2010, at the Conference of the Parties in Cancun to review and revise the progress of the Kyoto-Protocol, the so-called Technology Mechanism was introduced. It aims to “mobilize the development and transfer of clean technology to boost efforts to address climate change, getting it to the right place at the right time and for the best effect on both adaptation and mitigation.” The Technology Executive Committee (TEC), and Climate Technology Centre and Network (CTCN) have been formed to implement the technology mechanism. An important feature of this mechanism is the emphasis on private sector involvement and informal networks.

The task of the TEC and the CTCN is to support the development and transfer of technologies for mitigation and adaption. They are to

- provide an overview of technological needs and analysis of policy and technical issues
- consider and recommend actions to promote technology development and transfer
- promote and facilitate collaboration between policy, industry, research and non-profit organisations
- catalyse the development and use of technology road maps or action plans at international, regional and national levels.

The TEC is formed by nine members from annex I countries, nine from non-annex I countries[4] and one member each from a small island state and a least developed country. Whilst the TEC mainly provides policy advice to the Conference of the Parties to the UNFCCC, the CTC, hosted by UNEP, supports the practical side of the Technology Mechanism. It has the task to

- manage and respond to requests from developing countries
- foster collaboration and access to information and knowledge to accelerate technology transfer
- strengthen networks, partnerships and capacity building for climate technology and private sector involvement

1.5 Stakeholders in the RAC sectors

The RAC sectors show a high potential for technology transfer as their environmental impact can be highly reduced by advanced technologies. Technology transfer for green cooling involves a whole series of different stakeholders from government institutions to manufacturers and end-users of refrigeration equipment: Individuals, organisations and businesses who are seeking or offering climate-friendly cooling technology or related know-how, funding opportunities, or policy advice. Their action and interaction determine the rate, direction, and success of technology change. The main players are:

- Private sector: Manufacturers, industry associations, end-users, standardisation bodies, financial institutions; servicing companies, training centres
- Public sector: Governments, international organisations, government institutions, financial institutions, training and certification institutes
- Civil society: Non-governmental organisations (NGOs), research institutes (including universities), media, consumers

An important role can be attributed to the interaction between stakeholders of the three sectors. Technology change almost always involves stakeholders from at least two of the sectors. Previous examples of industry transformation

[4] Countries listed in annex I of the Kyoto protocol are industrialised countries and economies in transition. Non-annex I countries are developing countries. The country groups have different commitments under the Kyoto protocol in terms of CO_2 emission reductions and providing financial resources.

towards more environmentally friendly technologies show that the private sector plays a vital role in these transformations. However, consumers and environmental NGOs also have the potential to initiate change (as is illustrated in chapter 2). When tackling global issues such as climate change, ozone protection and social and environmental sustainability, networks between various stakeholders and across borders play an increasingly important role.

1.6 The Green Cooling Initiative (GCI)

GCI is a project funded by the International Climate Initiative (IKI) of the Federal Minister for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The aim of the Green Cooling Initiative (GCI) is to accelerate the transfer of environmentally friendly technologies in the refrigeration and air conditioning sectors to and between developing countries. These sectors have been identified as a growing market in developing countries with predicted rising greenhouse gas emissions and for which the necessary technology to significantly reduce emissions is already available for most of the RAC subsectors. The GCI wants to establish a global "Green Cooling Network" with several sub-networks, such as regional networks (Africa network) or sectoral networks (MAC network). The aim of the networks is to promote dialogue on green cooling and knowledge transfer between stakeholders from the private and public sectors and civil society.

More specifically, the GCI aims to initiate several exemplary technology cooperation projects with private sector involvement in developing countries that will lead to CO_2 emission reductions. The infrastructure for different networks will be provided and supported by a website containing information about the refrigeration and air conditioning sectors (www.green-cooling.org). On this website, GCI aims to provide sector-specific information that is interesting for members of the private sector wishing to invest in a certain country, policy makers that are seeking to reduce emissions in their countries, as well as civil society players who want to enhance their actions for green cooling. As much as possible, information on technologies, best-practice examples, regulations, capacity building, market trends and emission reduction potentials will be given on a country by country level. Additionally, the website will be a platform that can connect different stakeholders to form new networks or technology partnerships for the transfer of environmentally-friendly RAC equipment.

The first step in establishing networks is a systematic mapping of information, which is supported by this study.

GCI and the Technology Mechanism

GCI wants to enhance visibility of green cooling technology and the related mitigation potential in the TEC. Furthermore, the initiative offers support to this body when it comes to RAC specific policy recommendations, for example through Technology Road Maps and workshops with TEC members and observers. GCI also looks for opportunities to integrate its working groups or technology partnerships, once established, into the CTCN.

1.7 Content overview

Chapter 2 examines the stakeholder landscape and the dynamics of green cooling technologies spreading around the world. It highlights the role of different stakeholders and shows examples from the private, public and civil society sectors and their actions and activities involving the RAC sectors. Who are relevant drivers and what are the contributions of countries, NGOs, private sector stakeholders and others to sector transformation?

Chapter 3 describes the technical background of the refrigeration cycle and the methodologies used to compile and calculate data for chapters 4, 5 and 6.

Chapters 4, 5 and 6 look at the three subsectors UAC, MAC and AC chillers in more detail. Technical options to reduce GHG emissions from these subsectors in regard of refrigerants as well as energy efficiency are explored. The average energy efficiency in different countries is compared to energy efficiency regulations and mitigation potentials. The chapters also show the present and future global demand for units in these subsectors and resulting GHG emissions. The current market for the chosen subsectors is described in detail, including the main producing countries and the most important companies.

2 Stakeholders and Networks

The international effort to transform the RAC sectors to use ozone- and climate-friendly technology originates from the Montreal Protocol, an environmental treaty ratified by 197 countries. Increasingly, the focus is shifting from avoiding ODS to reducing the overall GHG emissions of the RAC equipment. This is addressed under the climate regime of the UNFCCC. Still, political treaties and regulations are not the only reasons why industry sectors change and also do not necessarily lead to an immediate reaction. There are broader dynamics, triggering innovation cycles, towards more climate solutions driven by several stakeholders. It is worth looking at all the players and stakeholders involved in the process of sector transformation to understand the dynamics, driving forces, chances and challenges.

State governments and government institutions are responsible for drafting national regulations and putting them in place. The private sector will have to implement the desired changes in terms of technologies. On the other hand, civil society players, such as NGOs or consumers, can also influence both the public and private sectors to bring green cooling technologies forward.

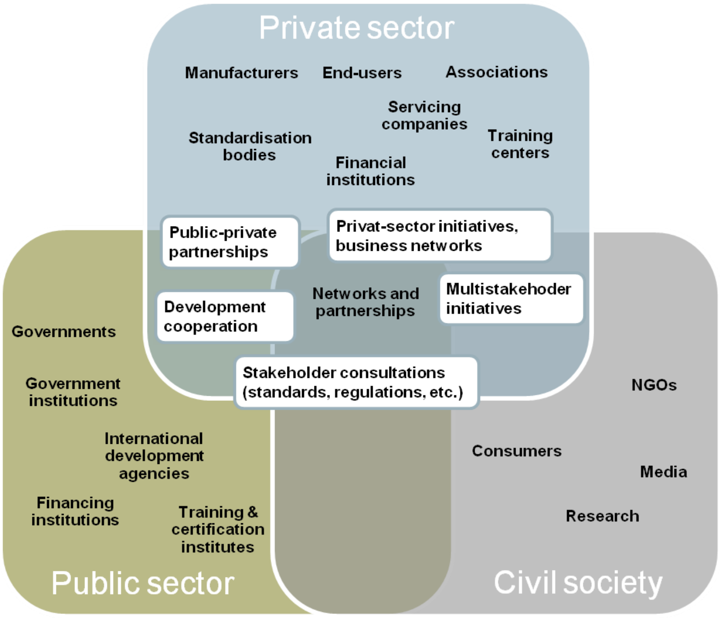


Figure 3: Stakeholders and networks in RAC technology

At this time, there is still significant potential to reduce greenhouse gas emissions through the dissemination of green cooling technologies – energy-efficient technologies using natural refrigerants. Some subsectors are more advanced than others, so they provide examples of dynamics that can advance green cooling in other sectors or other regions. Therefore, this section takes a closer look at the categories of stakeholders and provides examples of dynamics that have influenced the dissemination of green cooling technologies or have the potential to do so.

The individual chapters in this study on mobile air conditioning, unitary air conditioning and chillers will then take a closer look at the current situation, the main drivers and trends in these three subsectors.

2.1 The private sector

In the outcome document of the 2012 Rio+20 UN conference on sustainable development, the states emphasised their reliance on the private sector: “We recognize that a dynamic, inclusive, well-functioning, socially and environmentally responsible private sector is a valuable instrument that can offer a crucial contribution to economic growth and reducing poverty and promoting sustainable development“ (UNCSD, 2012).
In many cases, the private sector, usually in the form some major players, has both opposed change and driven change. Economic risk is likely a decisive factor for the private sector but it may not be the only one. It is therefore important to explore reasons for private companies to become laggards or front-runners in the sector transformation towards green cooling.

2.1.1 Manufacturers

Manufacturers of RAC systems and components are central and critical players in technology transfer within the RAC sectors. They are the ones to offer climate-friendly technology, to seek new solutions for their businesses or to block technologies that they believe to be a threat. Manufacturers can participate in technology transfer by driving innovation within their own business areas towards more climate-friendly solutions, which they can then put on the market and gain competitive advantages in the market.

Both the market – as determined by consumer awareness and demand – and the regulatory environment drive manufacturers to innovations, which can be measured by looking at patent files or transfers. A study on patents suggests that innovation of climate-friendly technology was mostly driven by energy prices until the 1990s and since then, environmental and climate policies have induced more innovation (Dechezlepretre et al., 2010). In terms of technology transfer, it is important to note that companies inventing new environmentally friendly alternatives will usually first file domestic patents only, as the innovation is developed specifically for a certain country. In a study on patents specifically for mobile air conditioning systems, inconsistent regulatory landscapes are found to be an important factor to limit the international diffusion of patents (Rave and Goetzke, 2011). If the invention is to be used in other regions, companies have to invest in additional R&D to adapt the patent to another country's specific conditions, such as climate or regulatory framework.

Other options for manufacturers to participate in sector transformation are to participate in collaborative research and development programmes, and to provide input to standard committees or stakeholder processes for new or revised regulations.

Drivers and dynamics - example 1

Climate friendly manufacturing innovation supported and driven by government kick-starting subsidies

Businesses in Germany that install a new energy-efficient commercial cooling system running on natural refrigerants can obtain a subsidy of up to 35% of the installation costs for the new system. From 2008 to 2013, subsidies of around 60 million Euros for over 600 modernised or new systems were granted. This programme is part of the German Environmental Ministry's Climate Initiative[5]. When a newly developed technology is more expensive than established systems, a government provision such as this German subsidy programme can assist manufacturers in making their climate-friendly products competitive. They are often more expensive because of logistical aspects such as the availability of parts and engineer expertise. Once these new systems have penetrated the market to a certain degree they become economically viable.

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☒

In addition to equipment and component manufacturers, chemical companies have considerable influence in the RAC industry. These companies develop and sell substances that are used as refrigerants. With growing international concern on the high GWP of fluorinated substances, increasing efforts are put into the development of so-called low-GWP refrigerants. The major players in this area are a few large companies, among them Honeywell and Dupont (USA), Arkema (France), Solvay (Belgium) and Mexichem Fluor (Mexico). Natural refrigerants are also provided by various companies such as HyChill (Australia), Settala Gas (Italy), Linde (Germany) or Puyang Zhongwei (China) to name a few.

[5] www.bmu.de/themen/klima-energie/klimaschutzinitiative/impulsprogramm-fuer-klimaschutzmassnahmen-an-gewerblichen-kaelteanlagen/

Due to international property rights and patents that apply to newly developed, synthetic refrigerants, every generation of these substances sees less companies competing. For example, u-HFC-1234yf is manufactured by two companies only – DuPont and Honeywell. DuPont and Honeywell are also cooperating in this area and the market has oligopolistic, sometimes monopolistic features[6]. A third company, Arkema has announced that it wants to start the supply of u-HFC-1234yf in 2016.

There is some conflict between manufactures of RAC equipment and chemical companies. More expensive refrigerants, such as u-HFC-1234yf mean higher profits for chemical companies but higher costs for equipment manufacturers.

Natural refrigerants are not yet readily available in every country or region. Availability of refrigerants also involves companies that do not manufacture but supply and distribute the substances. Especially in developing countries, availability can be an issue for both newly developed synthetic refrigerants and natural refrigerants. Synthetic refrigerants have to be manufactured by skilled people, knowhow is limited and production is controlled. There is a higher potential for profit, and therefore a high incentive for an enterprise to produce them. Natural refrigerants are mass commodities, which enables also small companies to process and sell them. Whether or not natural refrigerants are available in a country or region is an important factor in terms of infrastructure needed to manufacture and service green cooling equipment locally. Therefore, local supply networks play a critical role. Hydrocarbons are already widely used in some places, but their availability, and that of CO_2 as refrigerant, is still a barrier for the introduction of natural refrigerants in developing countries.

2.1.2 End-users

End-users vary considerably with the subsector in question. The main end-users for domestic refrigeration and room air conditioners are individual consumers and appliance retailers. Concerning commercial refrigeration, breweries, cold drink and ice cream companies operate fleets of display cabinets, drink fountains and vending machines. Big office buildings, hotels and data centres have higher cooling needs and use chillers and other commercial refrigeration equipment. Car manufacturers are the only direct purchasers of MAC devices. Different industries, supermarkets and food processing companies are all end-users of commercial and industrial RAC products.

Consumer brands such as beverage, beer or ice-cream companies are especially important in this context due to their global operation and recognition value. They have the potential to contribute greatly to the dissemination of climate-friendly technology by aligning their procurement strategy accordingly. Organisational changes affecting technology procurement within end-user companies can be driven by economic reasons (energy savings), risk analyses dealing with regulations and pressure from public opinion, and corporate environmental sustainability goals (emission reduction). Public awareness and environmental campaigns by non-governmental organisation (NGOs) can also exert pressure on consumer brands, and even push them into a front-runner role (see also Example 8).

Drivers and dynamics - example 2

Supply contract between end-user and supplier

The Coca-Cola Company committed to purchasing only HFC-free cold drink equipment by 2015, with CO_2 being the refrigerant of choice. To support this redirection in the company's procurement system, they signed a supply

[6] http://www.chemweek.com/lab/EU-Targets-DuPont-Honeywell-in-Refrigerant-Probe_39905.html

agreement over 1.1 million compressors with manufacturer Sanden Japan. This enabled the supplier to scale up their production[7].

Stakeholders involved: **Public sector** ☒ **Private sector** ☑ **Civil society** ☒

Corporate social responsibility

Businesses are facing more and more scrutiny from consumers, public institutions and non-governmental organisations. Consequently, corporate sustainability (CSR), environmental protection and climate change issues are entering the CEO level of corporations and business networks have become more prevalent. CSR plans have become a vital part of companies' strategic work, especially where strong brand recognition value is involved. These programmes are then presented in sustainability reports and related communication activities.

In this respect initiatives in the RAC sectors can also link for example to the "The Global Compact". The Global Compact was created to foster exchange on CSR. It aims to provide a platform for companies to align with UN agencies, labour and civil society to support fundamental principles in the areas of human rights, labour rights, environment and transparency and corporate governance. One of its 10 main principles, principle 7, refers to the precautionary approach, a principle that has become fundamental to international environmental agreements such as the Montreal Protocol (see Terms 1).

The relevance of CSR in the global context of sustainable development was also recognised by the Rio+20 conference where the signatories committed to „support national regulatory and policy frameworks that enable business and industry to advance sustainable development initiatives taking into account the importance of corporate social responsibility" (UNCSD, 2012). The relevance of business networks is also described in chapter 2.5.

2.1.3 Associations

Many countries have at least one industry association dedicated to the RAC sectors, such as the Brazilian ABRAVA or the Japanese JRAIA. Other types of associations range from those covering a specific subsector, for example the Southern African Refrigerated Distribution Association (SARDA) or the Indian Association of Ammonia Refrigeration (AAR), to international or regional associations, such as the Association of European Refrigeration Compressor Manufacturers (ASERCOM).

On behalf of their members, associations monitor and analyse market trends, conditions and trade practices as well as new or proposed legislation in their industry sector. Associations give a voice to their sector as opposed to an individual company and represent the businesses' interests towards national or international institutions, the media and the public. Associations also set up conferences or trade events. On behalf of their members, associations may participate in stakeholder consultations concerning refrigeration related regulations, and comment on the related developments externally to the media and internally to their members.

Drivers and dynamics - example 3

Industry participating in consultation processes on regulations

For a new directive on energy efficient commercial refrigeration equipment (Ecodesign), the Joint Research Centre (JRC) of the European Commission invited input from stakeholders such as manufacturers, consumer organisations and NGOs. Industry associations as well as individual companies provide data to the JRC, which is used in the

[7] http://www.coca-colacompany.com/sustainabilityreport/world/energy-efficiency-and-climate-protection.html#section-common-but-differentiated-responsibilities

preparation process[8]. Associations such as EPEE and Eurovent have also participated in other Ecodesign preparation processes such as on compressors and chillers, and in the stakeholder consultation about the European F-Gas Regulation[9].

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☒

Associations work in the interest of their members. If an associations' membership comprises mainly companies with little or no interest in developing or supporting alternative, climate-friendly technologies, then this association is unlikely to become a driving force in green cooling. However, some industry associations are already dedicated to natural refrigerants, such as Eurammon or the International Institute of Ammonia Refrigeration (IIAR). Many associations run their own websites with news on products, training opportunities etc.

Industry marketing network on natural refrigerants

Marketing company shecco offers online portals dealing specifically with natural refrigerant technology to connect likeminded companies[10]. shecco has been organising a series of "ATMOsphere" events, which deal with the developments in the natural refrigerants sector and bring together mainly companies already dedicated or interested in green cooling, specifically in using natural refrigerants.

2.1.4 Financial institutions (private sector)

Entering into new business sectors can cost businesses a lot of money: Activities range from conducting research, developing new products and building a new or converting an existing production line to raising awareness for climate-friendly products and training employees. Private companies, and especially small and medium size enterprises (SME), often depend on substantial loans when making organisational changes towards a more sustainable future.

This is where banks come into play: To make sure companies applying for loans will be able to pay back, banks expect them to explain their project plan and calculation for a return on their investment. By integrating environmental standards into their operations, banks are able to ensure a greater environmental efficacy with their customers. Many of the alternatives using natural refrigerants face higher upfront investment costs while operating costs are lower through the greater energy efficiencies of the appliances. Banks can here play a pivotal role lowering the entry hurdle by making new investments available for green cooling alternatives. Often, the access to loans is the biggest hurdle for new, energy efficient appliances, especially for SME.

Some banks already request that the environmental impact of an investment is considered. For example, the World Bank's private branch, the International Finance Corporation, lists resource efficiency and pollution prevention as one of their performance standards (IFC 2012). The Equator Principles (EP), which 79 financial institutions worldwide have adopted, also requires a minimum environmental assessment (EP, 2013). Banks could go one step further by considering minimum environmental performance standards, such as low-GWP requirements for loans concerning investments in RAC technologies. This may be a starting point for multistakeholder networks: Such a network could address and support financial institutions looking to include specific requirements in their environmental standards, such as for building loans.

8 http://susproc.jrc.ec.europa.eu/comrefrig/stakeholders.html
9 Position papers can be found on the associations' websites www.epeeglobal.org and http://www.eurovent-association.eu
10 e.g www.hydrocarbons21.com

2.1.5 Standardisation bodies

Standards are principally technical specifications as a voluntary self-commitment of the industry. However, national laws and regulations often refer to certain standards and thereby make compliance with them compulsory. With regards to refrigeration and air conditioning systems, especially those existing standards dealing with safety are relevant. They may present a barrier to the introduction of alternative, climate-friendly technologies because the technical options often rely on hydrocarbons, which are flammable substances, or on ammonia, which is higher toxicity or CO_2 which is very high pressure.

Among a variety of different standardisation bodies with regards to refrigeration systems, the main international organisations are the International Standardisation Organisation (ISO) and the International Electrotechnical Commission (IEC). At the European level, there are the Comité Européen de Normalisation (CEN) and Comité Européen de Normalisation Èlectrotechnique (CENELEC). Both international as well as both European committees collaborate in a way to align standards, which helps avoid contradiction of requirements in different standards. In addition, most countries have at least one national body that reviews and adopts international or European standards, or produces their own standards.[11]

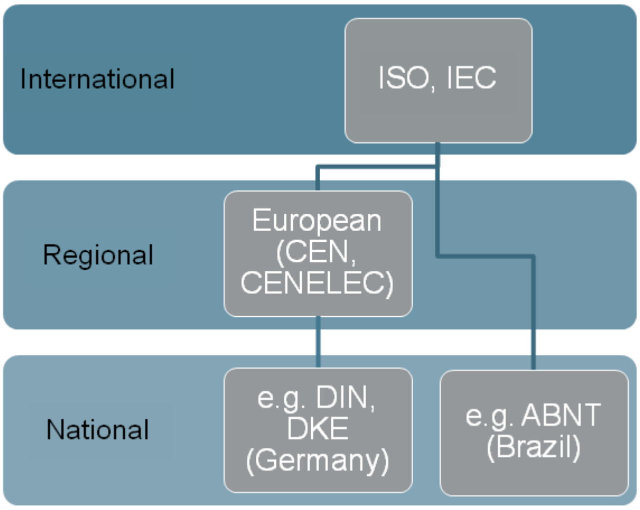


Figure 4: Standards organisations

While the organisations themselves are usually independent of governments and industry, the experts participating in the committees for drafting the standards are to a large extent industry representatives. With standards being under regular review, the manufacturing or end-using industry can in fact influence or even determine the content of standards. This is where private sector companies can assist to create enabling environments for the market entrance or dissemination of green cooling technologies. However, the opposite is true as well: Companies can also create enabling environments for synthetic, climate-damaging refrigerants and oppose changes in favour of natural refrigerants.

International standards are especially important for developing countries, which are often not able to develop their own standards due to missing resources (Snickars, 2002). Developing countries therefore often adopt international standards and integrate them in national regulations. Therefore, international standards on the safe use of natural refrigerants are likely to have global significance. In any case, if a country adopts an international standard for its national regulation, it is nevertheless advisable that this is done in a way that suits the country's specific conditions and needs.

Drivers and dynamics - example 4

Standardisation process in developing countries

The Swedish Standards Institute (SIS) and the Swedish International Development Cooperation Agency (SIDA) are organising workshops in developing countries to build capacity in standardisation processes and standards related to

[11] More detailed information on this in the GIZ handbook "Guidelines for the safe use of hydrocarbon refrigerants".

environmental topics. Workshops are targeted at people from industry, government and local NGOs. The following workshops are examples from their programme: Building institutional capacity on standard setting in the East African Community (EAC), CSR seminars in South Africa and Botswana and Climate related standards and the green economy: opportunities and challenges for developing countries in South Asia and East Africa[12].

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☑

2.2 The public sector

The transformation of a technology sector is also determined by policies such as energy efficiency regulations, or incentive programmes. These are driven by the public sector – governments on the national or regional (e.g. EU) level. Bans of substances damaging the environment or human health are anchored in international treaties.

Developed countries contribute to funds such as the Multilateral Fund of the Montreal Protocol. Developing countries on the other hand are responsible for devising their ODS phase-out plans and demand funds for technology transfer or capacity building programmes. International implementing agencies overseeing such programmes are also part of the public sector.

2.2.1 Governments and government institutions

Governments and government institutions play a vital role in the transformation of industry sectors as they can create – or prevent – so-called enabling environments. Opening markets to foster competition, and devising rules and regulations are approaches that governments can use to set the course for the innovation and introduction of new technologies in the RAC sectors. Measures to promote green cooling aim to reduce both direct and indirect emissions from RAC systems and appliances.[13] While policies often target either the refrigerant type (and its GWP) or the energy efficiency, they can sometimes be combined. For example, rewards for using natural refrigerants may be integrated into labelling schemes for buildings and appliances: The German product label “Der Blaue Engel” combines energy efficiency standards with the use of natural refrigerants and the UK BREEAM scheme provides additional points for using natural refrigerants.

Terms 2: Enabling environments

Enabling environments are a main component of the Technology Transfer Framework by the UNFCCC: “The enabling environments component of the framework focuses on government actions, such as fair trade policies, removal of technical, legal and administrative barriers to technology transfer, sound economic policy, regulatory frameworks and transparency, all of which create an environment conducive to private and public sector technology transfer.”[14]

Generally, in order to support sustainable growth in a country or region, government intervention needs to be based on a sound and well thought through rationale. It also needs to be checked regularly and amended if necessary to assure continuous effectiveness. In its innovation strategy project, the OECD emphasises that policies to stimulate innovation need to take account of changes in the global economy and the transformation of innovation processes (OECD, 2010). Where strong regulations on the use of fluorinated gases in applications are in place, industry will have to commit to drive the innovation and dissemination of more climate-friendly technology.

[12] http://www.sis.se/tema/The-International-Development-Cooperation-Department-at-SIS/Experiences/#CSR Seminars
[13] An overview of policy measures for the reduction of direct and indirect emissions in the RAC sectors is given in the module 8.1 of the GIZ handbook on NAMAs (GIZ, 2013)
[14] http://unfccc.int/ttclear/templates/render_cms_page?TTF_home

The European Union has the most comprehensive policy framework in place that affects the RAC sectors and supports the emergence and dissemination of green cooling technologies. The F-gas regulation[15] targets the use of high-GWP fluorinated refrigerants, as does the MAC directive for mobile air conditioning. Energy efficiency of appliances such as air conditioners is targeted in ecodesign directives[16] and with the European energy label[17].

Drivers and dynamics - example 5

Corporations driving regulation change

Until 2011, using HC-290 or HC-600a in commercial point-of-sale refrigeration equipment was not legal in the US. Starting in 2008, several companies such as Ben & Jerry's and Pepsico, introduced HFC-free bottle coolers and ice cream freezers to the US for trial, and initiated formal approval processes with the U.S. Environmental Protection Agency's (US EPA) Significant New Alternatives Policy (SNAP) Program. Hydrocarbon technology for various types of commercial coolers and freezers, as well as for household ones, was first approved by US EPA in 2011. Recently, Red Bull and their supplier Vestfrost submitted additional refrigerator types using R600a to EPA for approval, which was granted in 2013.

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☒

In the context of the Montreal Protocol and the phase-out of substances used as refrigerants, ministries or other national authorities can have decisive influence on the direction that the RAC sectors in their countries will go in. In particular, all so-called A5-countries have established National Ozone Units (NOU) that are responsible for managing the phase out of ODS in compliance with the Montreal Protocol. The Maldives, for example, are one of the leading developing countries in terms of phase-out of HCFCs, planning to stop using them entirely in 2020, ten years ahead of the globally agreed phase out target. This decision is motivated by both ecological and economic reasons: "Moving early to phase out the use of HCFCs not only helps protect the beautiful tropical environment tourists come to see but also positions Maldives as a strong eco-destination," commented Mohamed Nasheed, President of the Republic of Maldives (UNEP 2010).

Drivers and dynamics - example 6

Refrigerator labelling and recycling programme in Brazil

In Brazil, Minimum Energy Performance Standards (MEPS) for refrigerators, freezers and fridge freezers were adopted in 2007. In addition, electric utility companies have to invest 0.5% of their annual net revenues in energy end use efficiency programmes. This measure is known as the "Brazilian Public Benefits Fund". Between 2008 and 2010, as part of this programme, 45 electricity distribution companies replaced more than 380,000 refrigerators in low-income households at no cost, replacing old inefficient appliances with modern efficient appliances.[18] The households can save money and reduce energy consumption. For manufacturers of refrigerators, such a programme offers new sales opportunities. For the country, efficient appliances can help secure energy supply and avoid additional investment in new power supply.

Drivers and dynamics - example 7

Labelling information campaign in India

[15] http://ec.europa.eu/clima/policies/f-gas/legislation/documentation_en.htm
[16] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/index_en.htm
[17] http://ec.europa.eu/energy/efficiency/labelling/labelling_en.htm
[18] http://www.bigee.net/en/policy/guide/appliances/package/4/#gpp-specific-measures

India launched an energy star rating programme for refrigerators and air conditioners in 2006. For greater impact, the Bureau of Energy Efficiency (BEE) conducted a communication and awareness raising campaign to educate salespeople on the labelling scheme. The training was designed to provide participants with knowledge about energy efficiency and advise how to promote environmentally friendly products.[19]

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☑

Another possibility for governments to actively support green cooling technologies is via procurement practices: Public authorities are major consumers of products and services and their purchasing behaviour does influence the industries in their respective countries. The term "Green Public Procurement" (GPP) describes the process where public institutions procure goods and services with a reduced environmental impact as compared to such goods and services that would otherwise be procured. Many governments have integrated GPP guidelines in their regulatory framework. For example, the Chinese government procurement regularly publishes a list with environmentally friendly products for public procurement, which is integrated into the country's legal framework (CCICED 2011). GPP is primarily a voluntary instrument governments can employ. It can be promoted through networking and exchange of experiences such as through the International Green Purchasing Network[20] or the SCP Clearinghouse[21]. By including ambitious conditions regarding energy-efficiency and natural, low-GWP refrigerants in their public procurement standards, governments can serve as role models for green cooling and create awareness among employees and the private sector. They can thereby provide industry with strong incentives for developing green cooling technologies and products.

An overview of policy instruments that governments may apply to "green" the refrigeration and air conditioning sectors can be found in the GIZ handbook on NAMAs[22].

2.2.2 Development agencies and financing organisations (public sector)

The international effort to phase-out ODS under the Montreal Protocol is closely related to the international climate change regime. HFCs are often used to replace ozone-depleting substances in RAC technology, but as they contribute to global warming, HFCs are regulated under the UNFCCC and the Kyoto Protocol.

The main implementing organisations in the phase-out of HCFCs under the Montreal Protocol are multilateral implementation organisations such as the World Bank, the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP) and the United Nations Industrial Development Organisation (UNIDO). These organisations receive funding for their implementation work from the Multilateral Fund (MLF), through which developed countries provide substantial funds for technology transfer programmes in developing countries. Each so-called donor country may implement up to 20% of its contribution in bilateral projects. This is where donor countries' implementing agencies such as the German GIZ or the French Agency for Development (AFD) come into play: They put these bilateral projects in cooperation with the partner countries into practice. In addition, developed countries have individual funding programmes, such as the German International Climate Initiative, which has initiated several demonstration projects like the conversion of production lines for air conditioners in China and climate friendly chillers in Indonesia, both using HC-290 as refrigerant.

[19] http://www.beeindia.in/content.php?page=schemes/schemes.php?id=2
[20] http://www.igpn.org/index.html
[21] http://www.scpclearinghouse.org/
[22] http://www.giz.de/expertise/html/4809.html, module 8.1

Drivers and dynamics - example 8

Conversion of air conditioner production line

In a bilateral cooperation between India and Germany, the Indian company Godrej & Boyce converted one of its production lines to produce split air conditioners using the hydrocarbon propane as refrigerant. The project was funded by the German Environmental Ministry under its International Climate Initiative[23]. Activities also involved the training of production and service technicians in the handling of flammable hydrocarbon refrigerants. The project successfully established a best-practice model for India and the region. Consumers are now able to choose the "green" air conditioner model that is also highly energy efficient.

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☑

With programmes on resource efficiency and sustainable public procurement, UNEP for example also supports developing countries' efforts to initiate and implement green public procurement (UNEP 2012), which could in turn lead to industry incentives and the promotion of green cooling technologies (see previous section on governments and government institutions). Another source of funding for projects related to climate-friendly refrigeration and air conditioning is the Global Environment Facility (GEF). Among other projects, GEF has provided funding for the development and dissemination of solar powered refrigerators using natural refrigerants in Africa and Latin America (Solar Chill)[24].

Financing institutions such as the World Bank or regional development banks such as the African Development Bank (AfDB), Asian Development Bank (ADB), Inter American Development Bank (IADB) as well as other sub-regional development banks can link allocation of loans to certain criteria. At the World Bank, for example, environmental assessment is used to examine the potential environmental and social risks and benefits associated with its investment lending operations.

Where loans are requested for refrigeration and air conditioning equipment, specific standards concerning energy efficiency, leak prevention, and the use of low-GWP refrigerants could help give green cooling technologies a fast start.

2.3 Civil society

2.3.1 Non-governmental organisations (NGO)

Several non-governmental organisations (NGO) committed to protect the environment are supporting the phase-out of ozone depleting and climate warming substances. This has led to campaigns in RAC sectors, where NGOs advocate environmentally friendly alternatives for existing technologies: Foremost are Greenpeace and the so-called "Greenfreeze revolution" which introduced the first model of an F-gas free refrigerator in 1993. The technology, for which Greenpeace made sure no patent would apply, was quickly taken up all over Europe, and has spread to Asia, South America, and finally in 2011 to the US market.[25] Today, half of all refrigerators produced globally use natural refrigerants (TEAP 2013).

Drivers and dynamics - example 9

NGO action driving corporate action

[23] http://www.international-climate-initiative.com/en
[24] http://www.thegef.org/gef/project_detail?projID=4682
[25] www.hydrocarbons21.com/news/view/2746

NGOs do not necessarily highlight the subsectors with the highest CO_2 emissions from the RAC sectors but often focus on highly visible companies. Preceding the 2000 Sydney Games, Greenpeace requested major Olympic sponsors, specifically Coca-Cola, to not use HFCs at the so called "environmental Olympics". In 2004, the three companies Coca-Cola, Unilever and McDonald's, who had all been addressed by the Greenpeace campaign, created "Refrigerants, Naturally!", with Greenpeace and UNEP as founding supporters. Climate-friendly refrigeration has become a major part of the sustainability pledges of these companies. In 2009, CEO Muhtar Kent committed Coca-Cola to eliminating HFCs from all new point-of-sale refrigeration equipment in 2015.

Stakeholders involved: **Public sector** ☑ **Private sector** ☑ **Civil society** ☑

For Greenpeace as well as for other environmental NGOs, green cooling is usually one among various campaigns or focus points. Other NGOs include the World Wide Fund For Nature (WWF), the European Environmental Bureau (EEB), Noe21 or the Institute for Governance and Sustainable Development (IGSD). The Environmental Investigation Agency (EIA) has also been campaigning intensively for the phase-out of F-gases. Their activities include research, publication of reports and press releases, involvement in stakeholder processes on regulations, and engagement in the Montreal Protocol related meetings and discussions.

Another possibility for NGOs is to participate in standardisation processes. In Europe, for example, the organisations ECOS[26] and NORMAPME[27] specialise in this field.

2.3.2 Consumers

Individual households are the prevalent group of end-users when it comes to household appliances such as refrigerators, freezers and room air conditioners. Both environmental and economic benefits play a role here: Consumers are increasingly aware of the environmental impact that their product choice may have. Energy efficiency labels assist consumers in choosing environmentally friendly appliances. Even if the initial cost is higher, they can help save money in the long term. Labelling schemes related to energy efficiency are now common in many countries, not only in the European Union, the United States, or Japan, but also in Brazil, India and South Africa.

Looking again at "Greenfreeze", the introduction of hydrocarbon household refrigerators: It was only when Greenpeace ran a marketing campaign through which some 70,000 refrigerators were preordered that the first manufacturer converted its factory in order to produce these units[28]. The conscious decision of these consumers to opt for a climate-friendly alternative played a crucial part in the technology's successful market introduction.

In terms of finance, the sheer mass of consumers makes their contribution impossible to neglect, especially with increasing wealth in densely populated countries. The Climate Policy Initiative (CPI) mapped the overall climate finance investments in Germany for 2010, and concluded that private households made the largest single contribution to overall the country's climate finance that year. These investments were made in the building sector and came up to USD 18.6 billion, or 38% of Germany's total USD 49 billion German climate finance flows (Juergens et al., 2012).

[26] www.ecostandard.org
[27] www.normapme.eu
[28] http://www.deutschlandfunk.de/die-erfindung-des-gruenen-kuehlschranks.871.de.html?dram:article_id=240023 and http://www.greenpeace.org/international/en/publications/reports/fgases-history/

2.3.3 Universities and research institutes

Universities and research institutes are important actors for the refrigeration and air conditioning sectors. Their work can be commissioned by industry or public institutions or a combination of both. For example, the German Institut für Luft- und Kältetechnik (ILK) Dresden, an independent research institute, has been working together with a private company on the development of a chiller that uses water as refrigerant. The research was commissioned by the German Federal Ministry of Economics and Technology[29]. The Danish Technological Institute (DTI) is a partner in the Solar Chill Initiative aiming to bring solar refrigerators and vaccine coolers to developing countries. In developing countries, universities and other research institutes are often involved in their countries' HPMPs. One example for this is the University des Mascareignes in Mauritius, which cooperates with the government to establish a research and training platform on natural refrigerants, but there are many others as well. Most technical universities have refrigeration and air conditioning related research departments as parts of their Mechanical Engineering schools such as the ones at Shanghai Jiaotong University (China), Skopje University (Macedonia), University of Cape Town (South Africa), or the University of Ubertandia (Brazil) to name only a few.

2.3.4 Media

In spite of the fact that refrigeration and air conditioning contribute significantly to greenhouse gas emissions and global warming, different technologies and refrigerants are usually not widely discussed in the media. One example where media has shown interest is the discussion about the future of mobile air conditioning. The car manufacturing industry comprises some of the world's largest companies, such as Daimler, General Motors and Volkswagen. The decision concerning the future refrigerant choice of these companies will influence the entire servicing and component manufacturing sector around the world. The discussion focussed on both safety and climate issues. It was taken up in various media channels, from industry platforms such as r744.com[30] to major public broadcasters such as the German ZDF[31].

Drivers and dynamics - example 10

National ozone unit media workshops

The government of the Maldives plans to ban the import of HCFC-based equipment from 1 July 2014. In order to raise awareness among both consumers and industry about these regulations, the NOU sought the media's cooperation and organised a national media training workshop on ozone and climate. It was attended by 22 journalists and broadcasters from the country's print, broadcast and web media.[32]

Stakeholders involved: **Public sector** ☑ **Private sector** ☒ **Civil society** ☑

2.4 Sector transformation

2.4.1 Two examples: Sector transformation in MAC and domestic refrigeration

Before 1992, domestic refrigerators and mobile air conditioners used CFC-12 as refrigerant. This section looks at the transformation of these two subsectors that happened in response to the phase-out of CFCs. Both industry sectors had to look for alternatives and HFC-134a (with its GWP of 1,430) was an available technical alternative at that time. But the two subsectors went two different ways: Air conditioning in passenger cars was switched to HFC-134a

[29] http://www.ilkdresden.de
[30] http://www.r744.com/news/view/4510
[31] www.zdf.de/ZDFmediathek/beitrag/video/1865136/Frontal21-Sendung-vom-19.-Maerz-2013#/beitrag/video/1860468/Brand-im-Auto:-Gef%C3%A4hrliche-Klimaanlagen
[32] www.unep.org/ozonaction/News/Features/2013/MaldivesengagesmediaforHCFCphase-out/tabid/105970/Default.aspx

entirely while only roughly half of the world's domestic refrigerators produced today use HFC-134a – the other half uses climate-friendly hydrocarbons (TEAP 2013). Therefore, it is relevant to ask which factors were decisive to determine these transformations. The following scheme gives an overview about these subsector transformations and the predominantly involved actors.

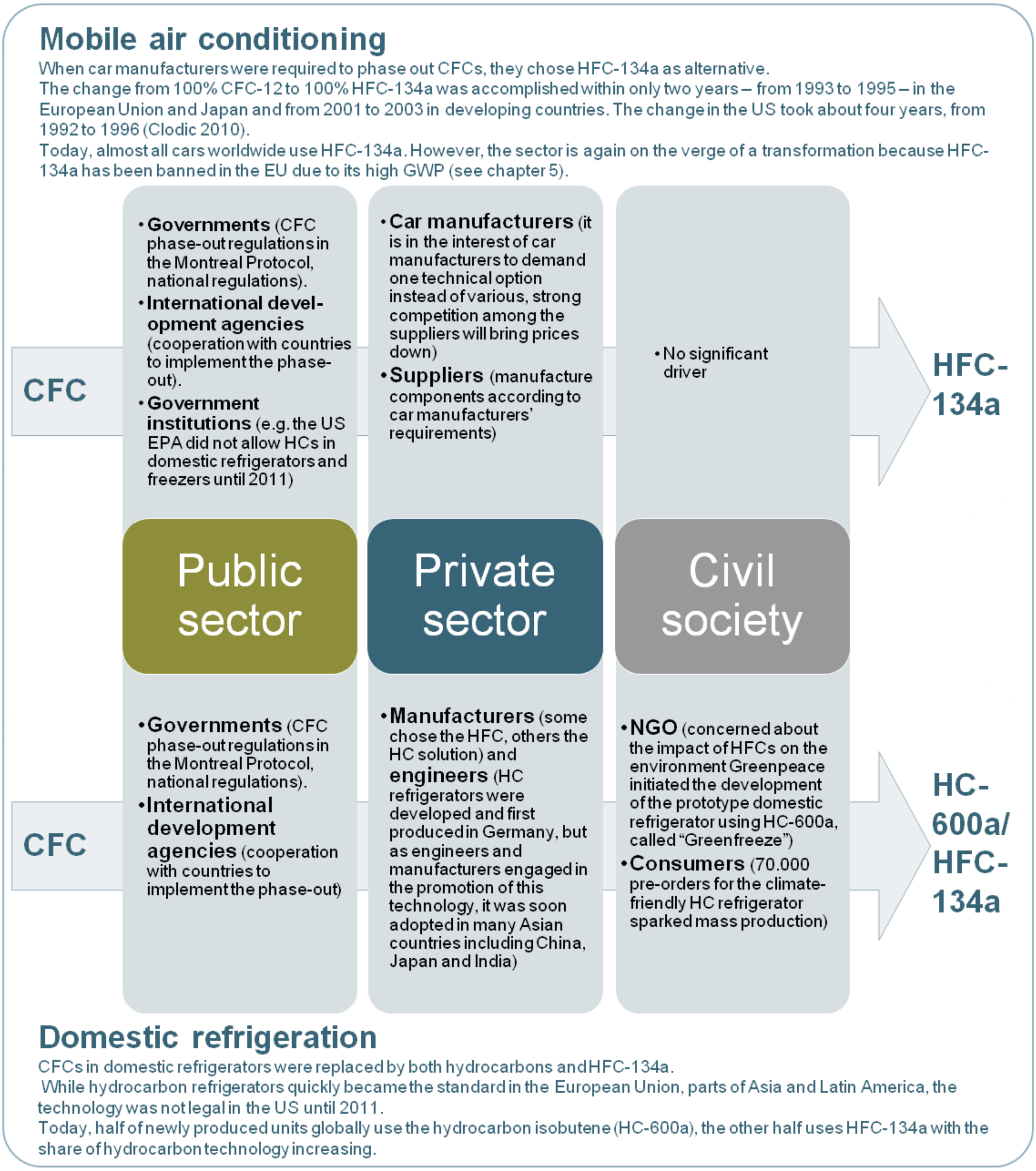


Figure 5: Overview of two subsector transformation processes

The Greenpeace “Greenfreeze” campaign can be identified as a major driving force in the transformation of the domestic refrigeration subsector. Greenpeace cooperated with engineers, manufacturers and consumers to bring Greenfreeze refrigerators on the market. The influence of the consumer also factors in: The Greenfreeze campaign induced some 70.000[33] preorders by consumers who wanted to buy the climate-friendly option. Without the NGO-led initiative to introduce hydrocarbons, the subsector transformation may have been towards HFC-134a as the only alternative, similar to what happened in the mobile air conditioning subsector. The mobile air conditioning subsector is today on the verge of transforming again as HFC-134a was banned for MAC in the EU because of its high GWP.

2.4.2 Overview of stakeholders and dynamics in the focus subsectors of this study

The following table summarises the current and potential dynamics that the various groups of stakeholders can engage in.

Table 4: Overview of stakeholders and dynamics

Stakeholders	Current and potential green cooling dynamics
Private sector	
Equipment manufacturers	▪ promote and apply labelling, MEPS and top-runner programmes ▪ demand their suppliers to develop/optimise technical option with natural refrigerants and high energy efficiency further, consider purchase commitments for certain components in order to scale up the suppliers’ industries ▪ run marketing campaigns to make green solutions visible to the buyer ▪ provide input to stakeholder consultations regarding standards and regulations ▪ form “innovation” coalitions and networks to promote green cooling solutions UAC ▪ pioneer in using HC instead of HFCs ▪ participate in funded projects to convert their production lines (MLF, bilateral funds) MAC ▪ pioneer in developing MAC with natural refrigerants (i.e. German car manufacturers choice for CO_2) ▪ provide servicing infrastructure of MAC systems with natural refrigerants Chillers ▪ Use HCs, CO_2 and ammonia as refrigerants ▪ participate in funded projects to convert their production lines (MLF, bilateral funds)
Suppliers of components	▪ produce technical options demanded by manufacturers ▪ provide input to stakeholder consultations regarding standards and regulations ▪ look for scaling up industries and will produce optimised components if these are demanded by equipment manufacturers MAC ▪ MAC manufacturer to innovate systems (i.e. electric compressors work efficient for cooling and as heat pumps) ▪ display and compete with high COPs/low-CO_2 labelling ▪ provide and innovate on components for MAC systems with natural refrigerants
Industry associations	▪ provide input to stakeholder consultations regarding standards and regulations MAC ▪ promote the use of MACs with natural refrigerants as global solution ▪ drive new industry standards for MAC systems with natural refrigerants Chillers

[33] http://www.deutschlandfunk.de/die-erfindung-des-gruenen-kuehlschranks.871.de.html?dram:article_id=240023

	▪ drive the development and application industry standards for chillers with natural refrigerants
Refrigerant producers and suppliers	▪ improve availability and supply infrastructure for natural refrigerants to foster scaling up of green cooling industries
Technicians, vocational schools	▪ train personnel to stay up-to-date to state of the art technology ▪ can profit as part of an emerging/growing infrastructure for green cooling industries can participate in internationally funded projects or partnerships to receive training
End-users	▪ operators can integrate green cooling requirements in their CSR programmes and procurement principles UAC and chillers ▪ hotel and office building operators can integrate green cooling requirements in their procurement principles
Financing institutions	▪ install low-GWP and energy efficiency related requirements for loans concerning investments in RAC technologies and buildings Chillers ▪ dedicated loan programmes for the use of low-GWP chillers
Public sector	
Governments and government institutions	▪ devise and enforce regulations or certification programmes regarding refrigerants, leakage etc. (i.e. ban/phase down the use of HFCs and promote the use of natural refrigerants instead) ▪ define tax and rebate programmes ▪ set up programmes for labelling, MEPS and top-runners, and integrate these into public procurement UAC ▪ ban the import/production of UAC with HFCs MAC ▪ ban the use of HFC-134a ▪ promote the use of natural refrigerants ▪ credit programmes regarding AC related fuel consumption Chillers ▪ tax incentives or subsidies for the use of very energy efficient chillers with natural refrigerant
International organisations	▪ coordinate phase-down of high-GWP HFCs ▪ provide information on technical options, capacity building for policy-makers
Financing institutions	▪ install low-GWP and energy efficiency related requirements for loans concerning investments in RAC technologies and buildings ▪ provide favourable loans for low GWP solutions (preferential loan requirements, interest rates etc.)
Civil society	
Research institutes and universities	▪ work with governments and industry on technical options ▪ strengthen international cooperation for to accelerate technology know-how transfer MAC ▪ cooperate with industry and public institutions regarding the dissemination of green cooling in MAC ▪ investigate the impact of TFA on the biological system
NGOs	▪ raise awareness on the global carbon footprint of UACs and global/national GHG reduction targets

		▪ bring attention to problems associated with HFCs ▪ petition governments to strengthen regulations
	MAC	▪ bring attention to problems associated with HFCs and fuel consumption
Media		▪ raise awareness on the global carbon footprint RAC sectors and global/ national GHG reduction targets ▪ bring attention to problems associated with HFCs
Consumers		▪ look for appliance labels and preferably buy green cooling technologies

2.5 The role of networks

Reducing environmental impact is not the sole reason for companies to convince others to work along with them. An important factor is that multi-stakeholder groups can have a more thorough impact on an industry sector, may attract more attention among the public. If big companies lead the way in demanding sustainable technology solutions for their businesses, the corresponding technology providers will have to scale up their economies as well. Thus the entire sector will profit from further development of products, improvement of infrastructure, and falling prices.

Understanding this potential, Greenpeace has established a branch called “Greenpeace Solutions”, where the focus is not on opposition to bad environmental behaviour of companies, but on collaboration and support of those front-runners who dare to make substantial changes: “We catalyze solutions to address global concerns. We engage with businesses, governments, and consumer markets so that one pressures the other to create dramatic improvements in our environment,” explains Greenpeace on the corresponding website.[34] Both “Greenfreeze” and “Solar Chill” are refrigeration-related campaigns within this Greenpeace branch.

The importance of cooperation and interaction of the private and the public sector in networks and partnerships is increasingly recognised. Multi-stakeholder “partnerships initiatives” among national governments, international institutions, the business community, labour groups, non-governmental organisations, and other actors as drivers for sustainable development were highlighted at the 2002 Johannesburg World Summit[35]. Efforts to create and maintain such partnerships come from both the business and the public sector.

Business networks exist on three levels and there is interaction between the levels. An important one on the global, overarching level is the World Business Council for Sustainable Development (WBCSD). It was founded just before the 1992 Rio conference, or “Earth Summit,” with the objective to assure the business sector would be consulted and its voice heard in the negotiations. It does not concentrate on one specific sector or technology, but issues related to refrigeration and air conditioning may be relevant when sustainable supply chains and mitigation of greenhouse gases is discussed.

The Consumer Goods Forum (CGF) is a global network of retailers, manufacturers and other stakeholder in the consumer goods sector. It has identified refrigeration as one of the important factors for their efforts to increase environmental sustainability in supply chains. In 2010, the CGF companies resolved to “begin phasing out HFC refrigerants by 2015 and replace them with non-HFC refrigerants (natural refrigerant alternatives) where these are legally allowed and available for new purchases of point-of-sale units and large refrigeration installations.”[36].

A business network specialised in commercial stand-alone refrigeration equipment is “Refrigerants, Naturally!”. The initiative promotes the use of natural refrigerants in cold drink equipment, ice-cream freezers and other commercial refrigeration equipment. The cooperation aims to support a positive regulatory and political framework for investment in climate-friendly technologies. The initiative consists of leading cold drink and ice cream companies and it is officially supported by Greenpeace and UNEP.

Linkages to TEC and CTCN

[34] http://www.greenpeace.org/usa/en/campaigns/global-warming-and-energy/green-solutions/
[35] http://www.worldwatch.org/rio-johannesburg-and-beyond-assessing-summit
[36] http://sustainability.mycgforum.com/refrigeration.html

With its Technology Mechanism, the UNFCCC approaches transfer of climate-friendly technology across all technology sectors. It explicitly recognises multi-stakeholder networks and their potential for scaling up technology transfer, and has therefore installed the CTCN. Its mission is to promote transfer of environmentally sound technologies for climate change mitigation.

The Climate Technology Network (CTN) is supposed to institutionalise networks to facilitate the cooperation on climate-friendly technologies. It is still in the process of being formed and could include everyone who is able to contribute to technology deployment and transfer, ranging from research institutes to non-governmental organisations and private sector initiatives. The Advisory Board to the CTCN is currently establishing this network of stakeholders.
. Since the dissemination of green cooling technologies can reduce emissions significantly, the RAC sectors should be dealt with under the Technology Mechanism.

3 Background on subsector analysis

3.1 Subsector characterisation

With products ranging from small MAC units in passenger cars to an industrial sized cooling facility in a dairy processing factory (see table 4), the RAC sectors are not a homogeneous industry. Accordingly variable are technical options to reduce emissions, which can therefore only really be looked at on a subsector basis. UAC, MAC and chillers are the subsectors that will be looked at in greater detail here.

Table 5: Overview of the refrigeration and air conditioning sectors

Sector	Subsector	Examples
Air Conditioning	Unitary air conditioning	Room air conditioner
	Chillers	AC chiller for the cooling of office buildings
	Mobile AC	Passenger car
Refrigeration	Domestic refrigeration	Refrigerators, freezers
	Commercial Refrigeration	Vending machines, integrated supermarket cooling
	Industrial Refrigeration	Condensing unit in food processing
	Transport Refrigeration	Transport of perishable foods in cooled lorries

3.1.1 Direct and indirect emissions

Direct emissions of refrigerant can occur during normal operation because of leaks from pipes and components. Without appropriate recovery and recycling facilities, most direct emissions occur when the refrigerant is exchanged during regular servicing or when a unit is dismantled (end-of-life emissions). Even though the amount of refrigerant in small units is only in the range of grams to a few kilograms, the high GWP of HCFCs and HFCs means that direct emissions contribute approximately 1/3 to total emissions from the RAC sectors.

Indirect emissions are due to energy consumption and contribute the other 2/3 of total emissions. These depend heavily on the source of electricity and how much CO_2 is emitted during its generation and are therefore different for each country.

Indirect emissions can be reduced by raising the energy efficiency of a product or by decarbonising electricity production. This study focuses only on potential CO_2 emission reductions achieved by energy efficiency measures; the introduction of less carbon intensive renewable energies is not accounted for in the calculations.

Both direct and indirect emissions are given in CO_2 equivalents. Direct emissions are weighted according to the GWP of refrigerants.

The refrigeration cycle

The refrigeration cycle follows the same principle for all applications in the different subsectors. Refrigerants are substances that absorb or release latent heat during a phase change (vapour to liquid and back). During the phase change from liquid to vapour, the heat is absorbed. This happens when the pressurised liquid refrigerant expands from the expansion device in the low pressure evaporator, which is a form of heat exchanger. Air or another medium is cooled at the evaporator's surface when the heat of the medium is absorbed. To prepare the refrigerant for the next cooling cycle, a compressor pressurises the refrigerant to a dense vapour, which then undergoes a phase change from vapour to liquid in the condenser. During this process, the refrigerant releases heat, which is transported outside the space that needs cooling. The heat transfer is supported through a heat exchanger. Electrical fans blow air over the evaporator and condenser to enhance the heat exchange.

Different applications require changes to the basic design, some of which are illustrated by the following examples: In cars and trucks the power to operate the compressor often comes directly from the motor. In chillers, water is cooled at the evaporator's surface instead of air, and can then be distributed over longer distances, for example in large office buildings.

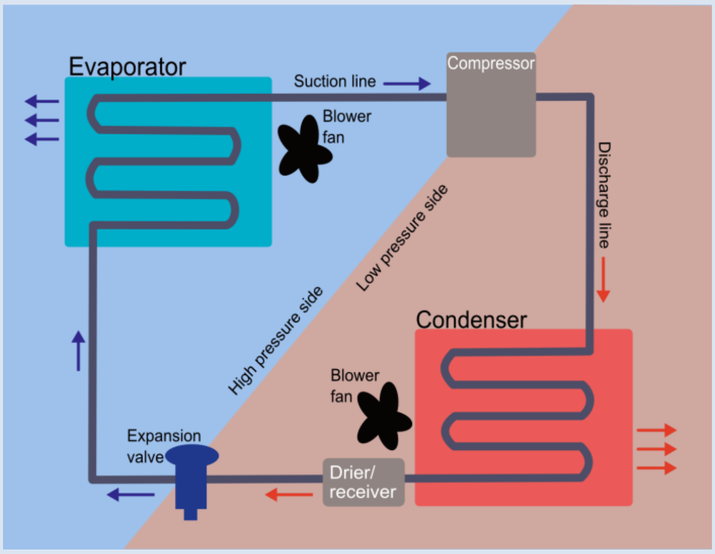


Figure 6: The refrigeration cycle. The refrigerant is under high pressure on the red side and heat is rejected. There is low pressure on the blue side and heat is absorbed

3.1.2 Emission reduction potentials

In order to transfer the RAC sectors to green cooling, both the direct and indirect emissions have to be reduced. There are several approaches to compare emissions from applications with different energy efficiencies and refrigerants that take both direct and indirect emissions into account. A life cycle assessment looks at all the emissions and negative environmental impacts from production to dismantling. Life cycle emission calculations only look at the direct and indirect emissions during manufacturing, operating and disposal. The TEWI emission calculation is a life cycle approach for appliances where the manufacturing emissions are not calculated. Manufacturing emissions are often difficult to calculate and generally have a minor impact on the overall life cycle emissions in the RAC sectors. It is important to note that some efforts to reduce one form of emissions can inadvertently increase another form of emissions.

3.1.2.1 Indirect emissions

The energy efficiency of products can usually be improved significantly, but numbers vary depending on the application. Whilst the improvement of energy efficiency can be cost effective to a certain point and decrease the life-time costs of the product, from a certain point onwards, each additional efficiency measure becomes disproportionately expensive. The following table shows general areas where energy efficiency improvements can apply. More details will be given for each subsector in the following parts of this chapter, but ultimately the potential is different for each product. As the energy efficiency also depends on the thermodynamic properties of the refrigerant, a change to a different refrigerant can also influence the indirect emissions.

Table 6: Areas of energy efficiency improvement

Area of improvement	Description	Example
System improvements	components in the system are modified or changed	higher efficiency compressor, more effective heat exchangers
Parasitic losses	electricity use due to parts not immediately used in the cooling cycle	more efficient fan/motors, standby/off mode energy use, alternative defrost methods
Cycle modifications	changes to refrigerant circuit that affects the thermodynamic cycle, sometimes necessary with natural refrigerants	cascade system, multi-stage compression, injection
Change in use	operation of equipment	electronic controls, behavioural changes

Terms 3: The Rebound effect

Some energy efficiency measures have shown a far smaller effect on energy consume than was estimated beforehand because the behaviour of users changed (Moezzi et al., 2009). Instead of predicted reduction in use, the appliance is for example run more often or another appliance is bought that was not affordable to run beforehand. The effect has been estimated to be between 0-50 % in space cooling (IRGC, 2013). In developing countries, the rebound effect can be especially high.

3.1.2.2 Direct emissions

Direct emissions can be eliminated by using the natural refrigerants CO_2, ammonia (NH_3) and HCs such as propane and isobutane. These natural refrigerants have zero or a negligible GWP. Natural refrigerants are already widely used in some of the RAC subsectors, such as domestic refrigeration (HCs) and industrial refrigeration (ammonia). However, not every natural refrigerant is suitable for every RAC subsector. For some applications there are safety restrictions on the use of natural refrigerants (flammability of HC, higher toxicity of ammonia). In other cases, they might not be compatible with current systems and technical changes would have to be made (e.g. CO_2 systems). The following parts of this study will describe which natural refrigerants are applicable for the subsectors and which special safety measures may need to be considered. Because of their environmental impact, u-HFCs will not be considered as an alternative to reduce direct emissions (see chapter 1.2).

3.1.2.3 Reducing cooling demand

Whilst the global demand for cooling is increasing rapidly, as discussed in the introduction to this study, not only changes related to RAC technology can make an impact. It is also possible to reduce the cooling demand of an individual building or space through changes in planning, design and behaviour. For example, by preventing a heat load to build up in a space, a lot of costs and energy can be saved as smaller or no refrigeration and air conditioning units have to be purchased and the run times can be reduced. Both direct and indirect emissions are reduced if smaller systems are used. The reduction of energy demand for heating and cooling that can be achieved through renovations and energy efficient building design is estimated to be up to 46% (BigEE, 2012).

Less cooling demand in the refrigeration subsectors is more likely to come from changed behaviour or better training of operators of commercial and industrial refrigeration equipment. Another example comes from supermarket display cabinets, where doors significantly reduce the energy use of refrigeration.

3.1.3 Lifetime CO_2 emission calculations

To illustrate possible emission savings, the lifetime CO_2eq emissions for each of the described subsectors have been calculated in a business-as-usual (BAU) case and compared to several emission reduction scenarios. These include both indirect emission and different methods of direct emission reduction. This approach was chosen as direct and indirect emissions have the highest impact on the environment in the RAC sectors. Refrigerant emissions during manufacturing are very small compared to those during operating and disposal. Results can be seen in the respective subsector sections.

3.1.4 Regulations and standards

Regulations and standards concern the use of both synthetic and natural refrigerants and are therefore important to the RAC industry. These can be restrictions on the use of refrigerants due to their environmental or safety impact.

For example, the Montreal Protocol and its phase-out plan for the use of HCFCs have been transferred into national laws. The long-term implications are a need to change to other refrigerants. Countries where HCFCs are banned already have import bans in place. Countries that have started the phase-out of HCFCs in 2013 have restrictions on the amount of HCFCs they are allowed to import. This amount is now decreasing until the effective phase-out in 2030.

The EU has also systematically restricted the use of HFCs. In its current review of the F-Gas Regulation the EU is also considering the effective phase-down of HFCs (Schwarz et al., 2011).

Some countries have introduced taxes on HFCs. The taxes are based on CO_2 equivalent, so that refrigerants with higher GWP are taxed higher. In some countries, such as Denmark, there is a refund of taxes if the refrigerant is returned for recycling or destruction. If there are no leaks, the tax becomes essentially a deposit scheme, giving an incentive to reduce leaks (Pachai and Harraghy, 2013).

Table 7: Countries with HFC taxes

Country	Tax	Introduction date
Denmark	20€/tCO_2eq 17.50/ kg HFC-134a	2003
Norway	39 € / kg HFC -134a	2002
Australia	25 $ /lb HFC -134a $24.15/t CO_2eq	2012
Sweden	35 € / kg HFC -134a	2010
Slovenia	2.88 € /t CO_2eq	2009
Spain	20€/tCO_2eq	2014

Taxes in Slovenia were considerably higher until summer 2013 (up to 16€/t CO_2eq). However, no taxes in neighbouring countries led to an HFC black market, rendering the tax ineffective[37]. Other countries, such as Poland and France are considering or planning the introduction of HFC taxes[38].

It is possible that a phase down of HFCs or the use of non-ODS alternatives will also be included in the Montreal Protocol. The Rio+20 declaration noted that the phase-out of ODS led to a rapid increase in the use of HFCs, and

[37] N. Masson, A. Maratou: shecco publications & upcoming GUIDEs and GUIDE+. Atmosphere, Brussels, 15/10/2013.
[38] A guide on HFC taxes in the EU will be published by shecco in December 2013, including a detailed overview of taxes and other fiscal measures.

recently, the G-20 in their St. Petersburg declaration as well as other political leaders' declarations, such as the CCAC have supported the idea that the Montreal Protocol will be instrumental to phase down HFCs. This would make use of efficient structures established under the Montreal Protocol Mechanism over years while the reporting of HFCs as a potent GHG would be continued under the framework of the UNFCCC. Proposals to amend the Montreal Protocol in such a way have been submitted since 2009 and a corresponding draft decision for the UNFCCC was submitted by the EU.

National laws on energy efficiency dictate Minimum Energy Performance Standards (MEPS), which set a minimum energy efficiency products have to conform to.

A standard is a "reference of achieving a certain level of quality", developed by a standardisation body on an international, regional (e.g. European) or national level or by an industry association (Corberan et al., 2008). Standards are not mandatory, but especially in developing countries without their own standardisation bodies, international standards are often adopted as national standards and sometimes made into laws.
Standards are continuously developed to reflect state of the art technologies and adopted by industries. As HCFC and HFC refrigerants are still the dominating refrigerants in most RAC sectors, most standards for RAC systems are based on these conventional refrigerants. There is a need to further develop and promote readily applicable standards for natural refrigerants. Model safety guidelines for natural refrigerants are to be developed so that their specificities can be considered by standards committees and integrated into European and international safety standard processes.

The main international and regional standards concerning refrigerants are listed below[39].

- ISO 5149: 2003 – Mechanical refrigerating systems used for cooling and heating – Safety requirements
- IEC 60335-2-24: 2007 – Specification for safety of household and similar electrical appliances. Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers
- IEC 60335-2-34: 2002 – Specification for safety of household and similar electrical appliances. Particular requirements for motor-compressors
- IEC 60335-2-40: 2003 – Specification for safety of household and similar electrical appliances. Safety. Particular requirements for electrical heat pumps air-conditioners, and dehumidifiers
- IEC 60335-2-89: 2007 – Specification for safety of household and similar electrical appliances. Safety. Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor
- ISO 817: 2005 – Refrigerants – designation and system classification
- EN 378: 2008 – Refrigeration Systems and Heat Pumps –Environmental Requirement

These standards often reference other standards, such as the standard dealing with explosive atmospheres, EN60079. EN60079 defines explosive atmospheres, gives guidelines on how to install electrical applications and protect equipment in these environments. Other examples are standards on components (e.g. piping (EN13480), pumps (EN809:1998) and leak testing (EN1779:1999)).
EN 378 is not harmonised with ATEX, the two European Directives on equipment (Equipment and protective systems intended for use in potentially explosive atmospheres) and workplace (Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres) in explosive atmospheres (BRA, 2010). However, there might be cases where ATEX applies to RAC equipment and conformity with ATEX should be checked especially if larger refrigeration and air conditioning systems with potentially high amounts of

[39] More information on standards relating to hydrocarbon refrigerants can be found in the "Guidelines for the safe use of hydrocarbon refrigerants" (GIZ Proklima, 2010).

refrigerant are installed. EN378 and ATEX are linked through the standard EN60079, which EN378 refers to and ATEX is harmonised with.
Another important standard for RAC equipment is EN13445-1 to -8 on unfired pressure vessels, which is harmonised with the EU Pressure Equipment Directive 97/23/EC. This standard is also frequently referred to in the standards dealing with refrigerants and refrigeration systems.

The transport of refrigerant cylinders and pre-charged equipment is covered in the ADR, the European Agreement concerning the International Carriage of dangerous goods by Road. For smaller numbers of cylinders, such as usually transported by service companies, only basic legislation applies. This includes ventilation of the vehicle, driver training, securing of cylinders and other simple safety measures (BRA, 2010).

Terms 4: Understanding energy efficiency terms

COP (Coefficient of Performance): This is defined as total cooling or heating capacity (W) per energy consumption (mainly electrical) (W).

EER (Energy Efficiency Ratio): Similar to the COP, but the performance is tested at one defined inside and outside temperature at full cooling capacity. Test conditions are derived from an ISO standard and vary slightly between countries but this does not lead to significantly different results (CLASP, 2011).

SEER (Seasonal Energy Efficiency Ratio): Several temperatures are included to account for different cooling needs during the course of the cooling period when a unit is not running at full capacity.

In the US the (S)EER is often given in the unit ‘British Thermal Units per hour’. A division by the conversion factor of 3.412 makes a comparison with the (S)EER in W/W possible.

IPLV (Integrated Part Load Value): One value is given that includes the efficiency while operating at various capacities. The efficiency at 100%, 75%, 50% and 25% capacity is measured and it is assumed that the unit runs at these capacities at 1%, 42%, 45% and 12% respectively of its running time (AHRI standard 550/590-2003). The percentages can be varied, given the NPLV (non-standard part load value).

MEPS (Minimum Energy Performance Standards): MEPS are set by some countries to eliminate less efficient products from the market and promote those with highest efficiencies. This is often accompanied with a labelling scheme providing information to customers. MEPS are usually increased stepwise to slowly transform the market to highly efficient products.

TEWI (Total equivalent warming impact): This concept takes into account direct and indirect emissions over the lifetime (excluding indirect emissions during production and disposal) and gives one number in CO_2 equivalents (Fischer et al., 1991).

LCCP (Life Cycle Climate Performance): The LCCP expands the TEWI concept to include emissions during manufacturing.

3.2 Production and demand

In order to set priorities for the technology transfer of green cooling technologies, it is important to know about the demand and supply for cooling equipment. In the context of technology transfer, the demand is primarily represented by developing countries, where the technology needs and the potential for improvement are generally high. Particularly those countries with growing economies, high population growth and high temperatures, represent a promising future market for green cooling technology. With the introduction of green cooling appliances, these countries can achieve the highest emissions reductions, covering their growing cooling needs on a sustainable basis (GIZ Proklima 2012b).

The phase-in of green cooling technology can represent a win-win situation for countries providing green cooling technologies and those with a developing market for green cooling technologies. Through the exchange of technologies new sustainable business opportunities can be developed. Companies providing technologies can make their advanced technologies available and gain additional market opportunities. Companies in countries with developing markets gain access to enhanced technologies and increase their long term competitiveness. Particularly because of the environmental benefits, the 16th session of the Conference of the Parties to the UNFCCC in Cancun (2010) decided to establish the Technology Mechanism to facilitate the transfer and implementation of green technology.

Technology transfer is not limited to import and export dynamics of technologies, but also includes the transfer of skills, knowledge and methods of manufacturing. This study focuses on the demand and supply to provide a general global market overview in the RAC sectors and the related market opportunities for green cooling technologies. A sound understanding of the dynamics is essential to initiate appropriate actions, such as bringing together supply and demand countries.

The demand for RAC equipment is driven by the cooling need. The demand is often referred to as 'market' or 'domestic sales'. Information about the current market and production of RAC equipment can be found in various reports, documents, websites and other statistical databases. However, estimating the future market is more difficult, which is either based on historical growth rates, expert judgment and sophisticated models including relevant demand drivers such as the future GDP growth, population growth and urbanisation.

Production and demand figures are taken from published statistical data. For each of the selected subsectors, the chapter on production and demand provides a global overview of the current demand and production situation. The chapters on UAC and chillers also include future projections of demand and emissions. The methodology used to derive production and demand and to estimate future demand and emissions is described in the following sections.

3.2.1 Methodology to derive production and demand

Unitary air conditioning and chillers

In order to assess the global unitary air-conditioning market and production side, literature from JARN (Japan Air Conditioning, Heating & Refrigeration News) Journal, BSRIA (Building Services Research and Information Association) reports and press releases, contributions of Multilateral Fund meetings, as well as numerous web resources, such as information derived from news portals, statistical institutions, financial reports, company profiles etc. were used.

Mobile air conditioning

The world MAC market is steered by the automobile manufacturers or original equipment manufacturers (OEMs), which commission a few direct (Tier 1) system and component suppliers to develop and manufacture tailor-made MAC solutions for each new car model. Through the OEM-supplier dependency it is possible to analyse the MAC market using data on automobile production and sales. The MAC market size can be estimated based on available data of newly manufactured cars and the share of the fleet equipped with MAC systems. The production of cars and MAC systems is fairly synchronous as the mode of delivery between automotive MAC supplier and the OEM is based on 'just-in-time' logistic systems. This study focuses on country-level passenger car production and demand. Regarding passenger car sales and production, data sources such as the OICA (Organisation Internationale des Constructeurs d'Automobiles or the International Organisation of Motor Vehicle Manufacturers) were used. Besides published data, additional information from a survey among major MAC suppliers at the Internationale Automobil-

Ausstellung in Frankfurt am Main, Germany, on 18 September 2013 (IAA, 2013) was integrated for a more detailed understanding of the global market.

3.2.2 Estimating current and future numbers of appliances in use, unit sales, and emissions

To estimate present emissions and their future development, a comprehensive modelling approach was applied. The first step was to model the stock, i.e. the number of appliances in use in the various countries. Unit sales were derived from the stock, while both unit sales and stock figures were used to calculate the emissions using a vintage bottom-up stock model (see

Figure 7).

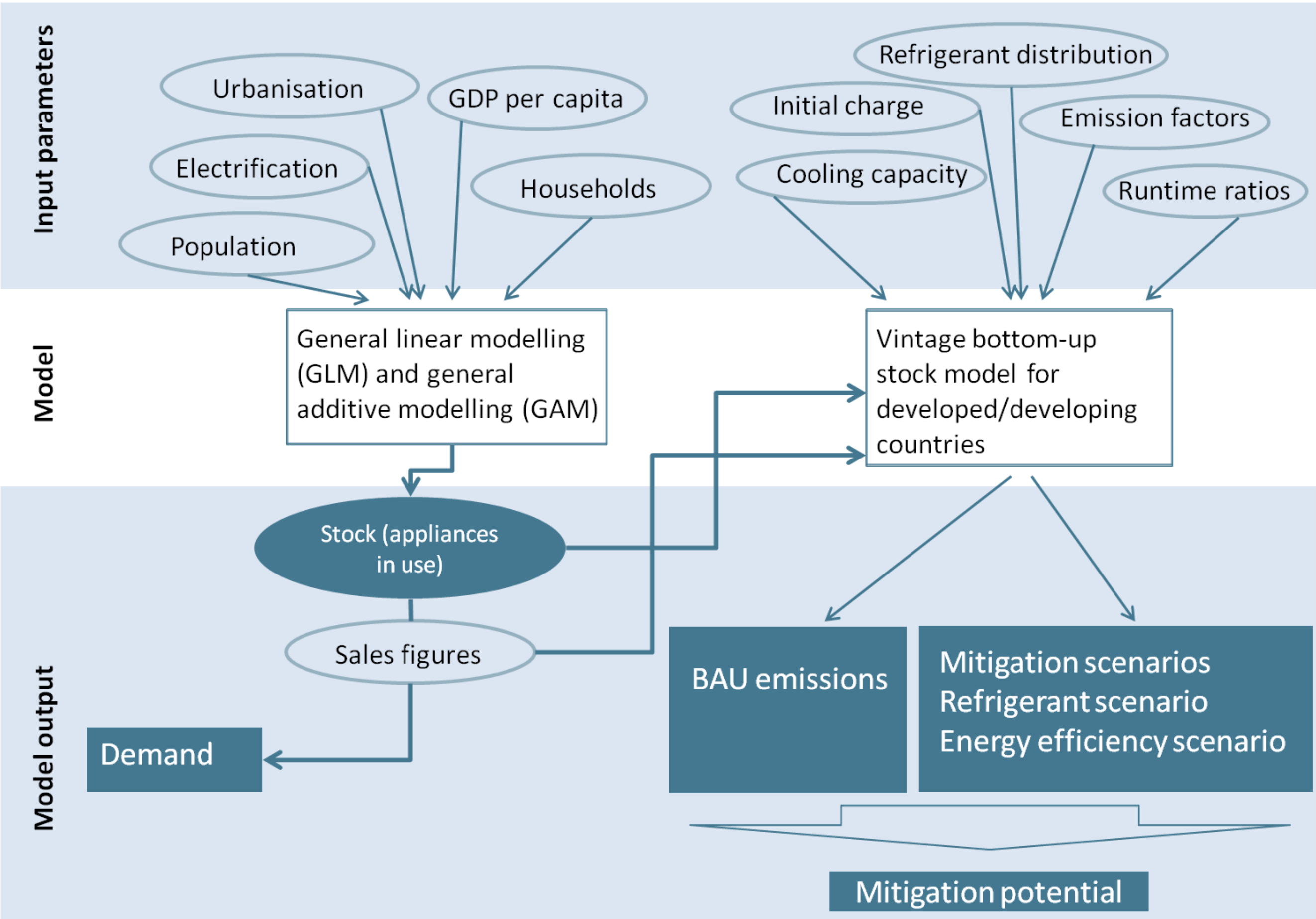


Figure 7: Modelling framework to derive future demand, emission scenarios and mitigation potential

Step 1: Modelling the stock

In a sophisticated modelling approach, which was chosen to estimate the stock for selected appliances, a relationship is built between the current response (stock, diffusion rate, ownership) and current predictor variables. The following predictors were considered:

- Population
- GDP
- temperature index
- urbanisation
- electrification rates

For these variables, plausible future predictions exist. Specifically, generalised linear models and generalised additive models were used to model the stock accordingly.

This detailed approach requires very specific information regarding the response and predictors, and is thus limited to RAC systems with a sound database to calibrate the models. It was possible to use this method in the following subsectors:

- split residential air conditioning systems
- MAC systems in passenger cars
- domestic refrigeration (not shown in this study)

Ownership data for UAC systems, which are dominated by split residential systems, were collected for selected countries through a comprehensive literature research using primarily, but not only, BSRIA and JARN documents.

The number of cars for selected countries was taken from the World Bank database, given as passenger cars per 1000 inhabitants[40]. In order to derive the number of MAC systems, the average percentage of cars containing air conditioning systems (Schwarz et al., 2011) was applied to the modelled absolute number of cars. Different factors were used for developed and developing countries.

Penetration rates for domestic refrigerators were taken from McNeil & Letschert (2008). These values represent the responses in the sophisticated GLM and GAM modelling approach.

The stock of AC chillers could not be modelled using this sophisticated approach due to lack of data.

Step 2: Calculating unit sales and market values

The modelled stock was used to derive unit sales figures, taking into account that a certain part of the equipment is decommissioned at end-of-life. Multiplying the unit sales figures by current unit market prices results in market value estimates.

Step 3. Modelling emissions, BAU and mitigation scenarios

The stock and unit sales figures were then used to calculate current and future CO_2 emissions, accounting for direct (refrigerants) and indirect (energy consumption) emissions. For this calculation, a vintage bottom-up stock model was used, considering additional parameters such as initial charge, cooling capacity, emission factors for each of the appliance types.

In order to assess the effect of mitigation strategies two different scenarios were calculated: a business-as-usual (BAU) scenario and a mitigation scenario which considers the change of the refrigerant and system design and improvements in the energy efficiency. A comparison between the BAU scenario and the mitigation scenario results in the mitigation potential.

Calculations were done separately for developed and developing countries as the type of equipment, energy efficiency and refrigerants differ substantially.

A full description of this vintage bottom-up stock model can be found in module 1 of the GIZ technical handbook on NAMAs in the RAC&F sectors (GIZ 2013).

[40] http://data.worldbank.org/indicator/IS.VEH.NVEH.P3

4 Unitary air conditioning (UAC)

4.1 Subsector characterisation

4.1.1 Overview

The subsector UAC contains ductless split, ducted split and rooftop ACs as well as VRF systems and self-contained units, which are movable ACs and window/through-the-wall units. As split residential ACs make up 80% of the UAC market (in terms of numbers of units) and are therefore by far the most important subsector of UAC, they will be looked at in more detail in the following section. Split residential ACs consist of two modules; one of which contains the compressor, outdoor heat exchanger and expansion device and is installed outside. The other module with the indoor heat exchanger is placed inside in the room. In cooling mode, air is cooled by being blown over the indoor heat exchanger, which is being used as an evaporator. The modules are connected by refrigerant piping. In reversible ACs, the cycle can be reversed and used for heating, so that the air blown over the indoor heat exchanger is warmed, due to it being used as a condenser. The refrigerants in split AC are mainly HCFC-22 in developing countries or R410A (an HFC mixture) for developed countries. For new units, developed countries have fully phased out HCFCs and developing countries are progressing with the phase-out of HCFC for newly produced units.

Inverter technology is used in many new units as they can help with improving the energy efficiency during part load operation. Inverters enable the control of the compressor speed according to the cooling demand, thereby reducing the so-called cycling losses that are present with on-off control.
The energy efficiency is given as Energy Efficiency Ratio (EER) or Seasonal Energy Efficiency Ratio (SEER). This refers to the whole system compared to cycle COPs/EERs, which would only look at the efficiency of the refrigeration cycle, neglecting losses due to fans etc. The SEER is a time-weighted average of different COPs based on (normally four) different temperature conditions present in the country or region under consideration. Because lower temperatures, where the AC runs at less than full-capacity are included in the SEER, it is higher than the EER.

End-users for ductless split ACs are predominantly private consumers and households.

4.1.2 Energy efficiency trends

Figure 8 shows the trend of the average EER of available products over the last 10 years as well as the highest and lowest EER available (shown by the error bars). Only some selected countries are shown for better readability. The strong increase in EER for the best available products, e.g. from 4 in 2005 to above 6 in 2011 in China, shows the high technological potential. This is not reflected in the average value because EERs in the least efficient products are almost stagnant. In the EU, these have even decreased from 2.5 to 2.2 in the presented time period. China is an exception, with a significant EER increase in the least efficient products, which is reflected in a slight increase in overall product efficiency. In general, the best available products in developed countries have higher EER than in developing countries but other differences in the average of available products or in the least efficient products are small.
The reason for comparably high EERs in Japan and China is the high penetration rate of inverter technology. For this 10-year trend, EER data has been used because SEER is a fairly new concept where comparative data is still not sufficiently available.

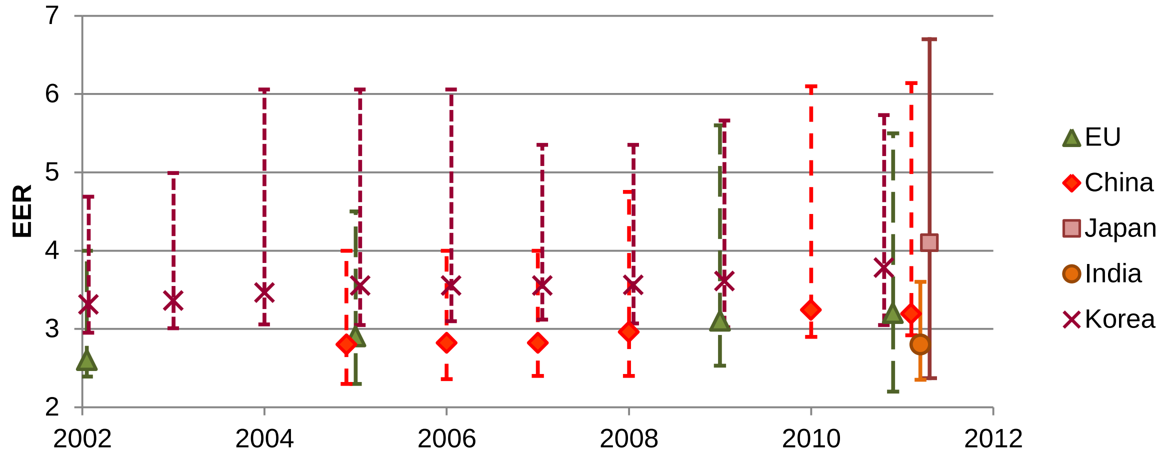


Figure 8: Trend of Average EER in selected countries over the last 10 years. The error bars show the lowest and highest EER available. Source: IEA (2011), CLASP (2011), SEAD (2013)

Table 8 Average EER values from selected other countries

Country	EER	Date	Source
Australia	3.16	2011	IEA, 2011
Brazil	3.19	2011	SEAD, 2013
Canada	3.6	2011	SEAD, 2013
China	3.19	2010	CLASP, 2011
EU	3.2	2011	CLASP, 2011
Ghana	2.52	2006	IEA, 2007
India	2.8	2011	SEAD, 2013
Japan	4.1	2011	CLASP, 2011
Korea	3.78	2011	IEA, 2011
Malaysia	2.93	2004	DMG, 2004
Mexico	2.92	2011	SEAD, 2013
Russia	2.79	2011	SEAD, 2013
South Africa	2.91	2011	SEAD, 2013
Thailand	3.16	2004	DMG, 2004
United Arab Emirates	2.69	2011	SEAD, 2013
US unitary	3.04	2010	CLASP, 2011
Vietnam	2.2-3.9	2008	CLASP, 2009

4.2 International and national regulations

The phase-out of HCFCs under the Montreal Protocol and taxation on HFCs (as described in chapter 3) are the main regulations concerning refrigerants in the UAC subsector.

Many countries have MEPS guidelines for AC. These can differ for cooling capacity or GWP of refrigerant and are sometimes increased step-wise to cut out the least efficient products.

Figure 9 shows MEPS for Japan, Korea, China, the EU and India and Table 9 lists other countries with MEPS that have not been included in the graph. Bolivia, Colombia, Ethiopia, Indonesia, Jordan, Lebanon, Malaysia, Nigeria, Pakistan, Senegal, Serbia and Ukraine are all planning to introduce MEPS (WEC, 2013).

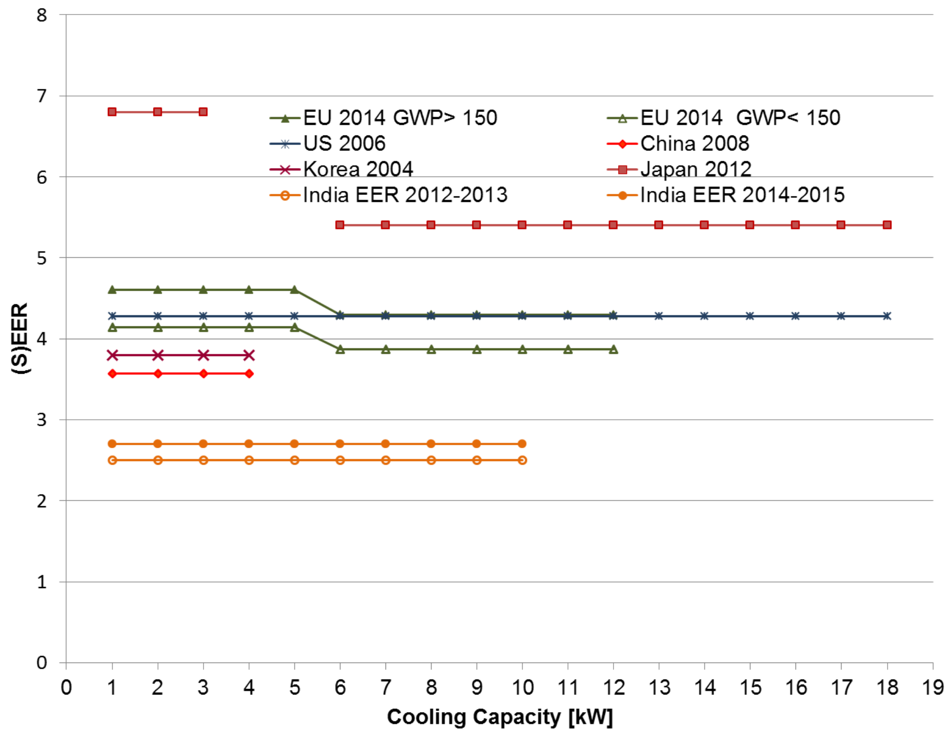


Figure 9: MEPS for (S)EER values in selected countries. EER values are shown for India (orange).

Table 9: MEPS from selected other countries. The reference WEC, 2013 refers to countries that have MEPS according to the World Energy Council, but no specified values could be found.

Country	MEPS standard
Albania	WEC, 2013
Argentina	WEC, 2013
Australia & New Zealand	3.3 (< 5 kW) 2.9(5-10 kW) 2.7(11-18 kW)
Canada	WEC, 2013
China	see graph
Costa Rica	WEC, 2013
Egypt	WEC, 2013
EU	see graph
Ghana	2.8
India	see graph
Iran	WEC, 2013
Israel	WEC, 2013
Japan	see graph
Korea	see graph
Mexico	2.72
Philippines	2.52 (>12 kW) 2.67 (< 12 kW)
Singapore	WEC, 2013
Sri Lanka	WEC, 2013

Taiwan	3.5 (<4kW) 3.2 (> 4kW)
Thailand	2.53 (8-12 KW), 2.82 (< 8kW)
Tunisia	WEC, 2013
United Arab Emirates	WEC, 2013
USA	see graph
Vietnam	WEC, 2013
Vietnam	WEC, 2013

Newer MEPS give SEER requirements as they are thought to reflect real conditions better. Apart from India, the SEER values are given and these have been adjusted so that small differences in the testing method are accounted for (CLASP, 2011). Lower values for the average EER in Figure 8 than MEPS shown in Figure 9 can be explained because SEER is always higher than EER.

Highest MEPS are found in Japan. Japan's high MEPS are also reflected in the high average EER in Figure 8. The same is true for Korea, where an early introduction of MEPS has led to consistently high average and high efficient EERs over the years. However, no huge improvement in the average EER can be seen since the introduction of the MEPS in 2004. In China, the introduction of MEPS in 2008 led to a significant improvement in the least efficient product category. In India MEPS are in effect since 2010 and the worst efficient products are on the same level as in Japan. In the EU, where MEPS were only introduced in 2013, the least efficient product is the worst shown here. This shows the high effectiveness of MEPS in increasing the energy efficiency of products in the market.

MEPS are introduced increasingly more by developing countries in order to secure energy supply and to protect the market from an inflow of cheap inefficient products from other countries (CLASP, 2002). The introduction of MEPS is often coupled with public campaigns to promote energy efficient appliances and their benefits for households. Labels are introduced to make energy consumption comparable. Examples come from Ghana, where AC MEPS were introduced as early as 2005 and from India, where MEPS came into effect in 2010. India has published a benchmarking tool where the annual costs of running ACs from different efficiency classes can be compared[41].

4.3 Scope of improvement

4.3.1 Alternative technologies - refrigerants

The following, refrigerant-related changes will lead to savings in direct emissions:

- A switch to natural refrigerant with low GWP (in particular HC-290/HC-1270) will eliminate nearly all direct emissions. Special safety measures include a maximum charge size, special design of certain electrical components and installation instructions.
- Reducing refrigerant leakage by changing the design, improving maintenance, and reducing the charge size. Introducing effective recovery and recycling reduces end-of-life emissions.
- Substitute the use of many splits with a distributed water-cooled system or district cooling, thus greatly minimising the use of refrigerants. This option is advisable for new building developments as an alternative to small ACs but depends on the local situation.

Challenges: Because NH_3 is toxic, it should not be used in space occupied by human beings and is therefore not used in residential air conditioners. COPs of UAC CO_2 systems are too low, in particular in high ambient environments, without cycle modifications, which are not economical for small appliances.

[41] http://www.saveenergy.co.in/

4.3.2 Energy efficiency

The possible improvements in energy efficiency depend on the unit under consideration, already existing EER, the refrigerant, climatic conditions and cooling capacity. The ideal refrigeration cycle, assuming constant load, infinite sized heat exchangers and 100% efficient compressors has a COP between 32 and 36 (depending on the refrigerant used), which of course can never be reached completely. This nevertheless leaves a high potential for energy efficiency improvements. The following values are guidelines and it can be seen that the range is often very high.

- The most important approach is optimised components, such as the compressor and the heat exchanger.
- Because the majority of AC units are not running at full capacity most of the time, a high energy saving potential in split ACs comes from introducing inverter technology, allowing the units to run at less than full capacity.
- ACs using HCs as refrigerants have higher efficiencies than CFCs, HCFCs or HFCs. The extent of this is under debate and has been found in experiments to range from 2% (Park and Jung, 2007) to 30% (Wang et al., 2004).
- Smaller, but consistent electricity savings can be reached by reducing losses in the standby or off modes. This is especially the case for smaller units and in climates where the AC is not always running.

Figure 10 shows the average SEER in 2011, and the potential economic and technical improvement (data from SEAD, 2013). The economic potential depends mainly on electricity prices. Higher unit costs for more efficient products are balanced by lower electricity bills during the lifetime of a product. In countries with high energy costs, such as Japan, the economic potential is close to the technical potential. The potentials for technical improvement are dependent on country specific climate and seasonal conditions and take into account realistic compressor efficiencies.

4.3.3 Reducing cooling needs

Similar to other energy intensive sectors, it is worth looking at possibilities to reduce demand for cooling from UACs. An option to reduce cooling needs altogether is to integrate cooling in the design of new buildings. Architecture developed over the centuries in hot countries often features cool yards with fountains and shaded rooms with few windows facing the sun. Cooling needs can be reduced by a building's shape and orientation, shading and thermal insulation[42]. Green roofs, windows with low solar transmission and light colour materials can all contribute to lower heat loads in hot climates[43].

Table 10: Energy efficiency measures in UAC

	Measure	Improvement COP
Cycle improvements	Inverter/variable speed Compressor Heat exchanger	20-24.8% 6.5-18.7% 9.1-28.6% (SEAD, 2013)
Parasitic losses	EU: Standby Crankcase heating and control	0.8-9% (lower capacity, higher savings) (Armines, 2009) 9.8-10.7% (SEAD, 2013)
Refrigerant	HC	4 % (Park et al., 2007) up to 30% (Wang et al., 2004)
Change in use	Occupancy sensor	

[42] http://www.bigee.net/en/buildings/guide/residential/examples/
[43] http://www.bigee.net/en/buildings/guide/residential/cases/

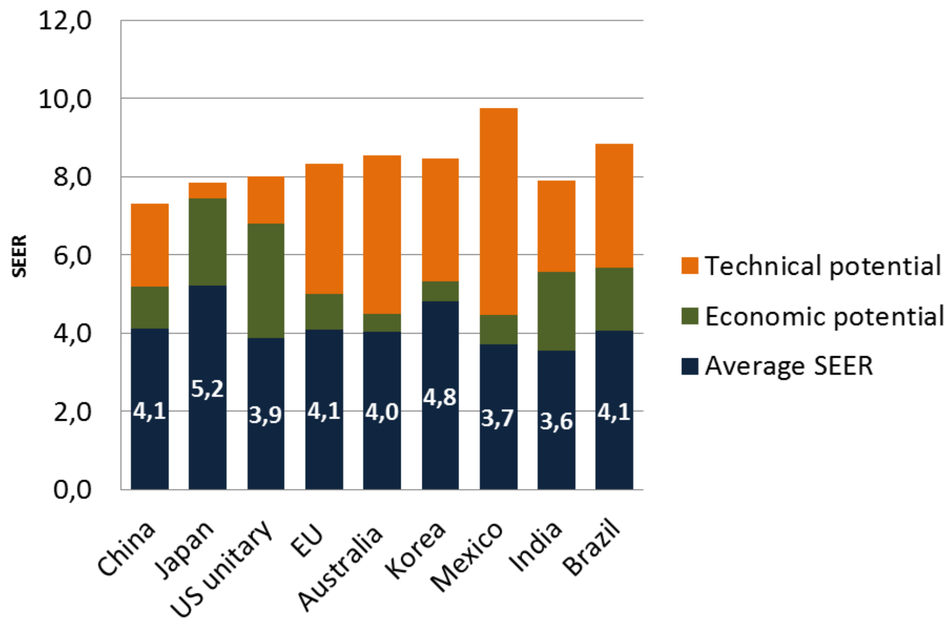


Figure 10: Average SEER, Economic and Technical potential in selected countries. Source: SEAD, 2013

4.3.4 CO_2 emissions over lifetime

Figure 11 shows the lifetime CO_2 emissions for split residential AC in industrialised (dark blue and dark red) and developing countries (light blue and orange). The BAU scenario is compared to several scenarios including indirect and direct emission reductions. Combining energy efficiency improvements with the introduction of a natural refrigerant can lead to CO_2 emission reductions of about 60% compared to the current BAU applications. As leakage rates are usually higher in developing countries and the average energy efficiency is lower, emissions in developing countries are higher. Assuming the same technology as in industrialised countries could be applied through the transfer of environmentally friendly options, the potential of emission reductions lies at around 70%. Reaching the same energy efficiency as industrialised countries would obviously take developing countries longer. These calculations do not take into account the decarbonisation of electricity generation, which could reduce indirect emissions significantly.

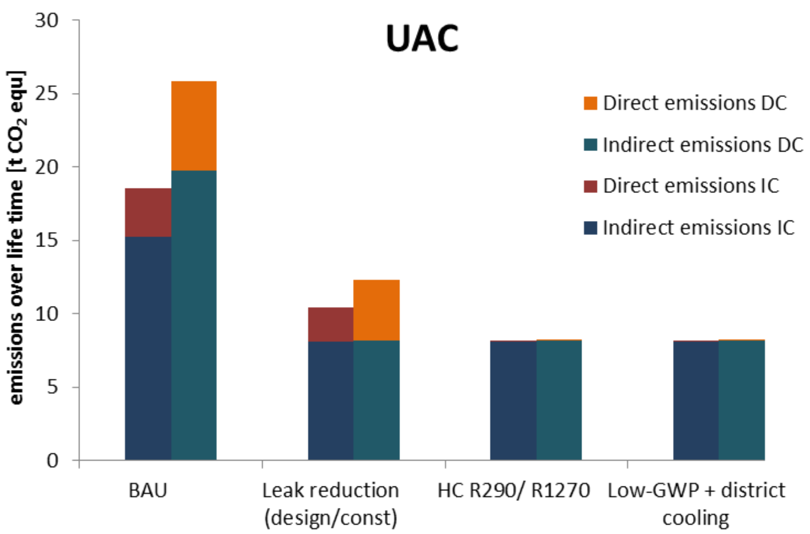


Figure 11: Life time CO_2 emissions in unitary split air conditioning for the business as usual and several emission reduction options in industrialised (IC) and developing countries (DC). An average value has been applied for IC and DC as there are significant differences within those country groups.

4.4 Production and Demand

4.4.1 Overview

The UAC market size in 2012 was estimated to be approximately 105 million units, which corresponds to a market value of USD 73 billion. The UAC subsector is divided into the sub-categories ductless splits, ducted splits, rooftop ACs, VRF systems and self-contained units, which are movable ACs, window/through-the-wall units and packaged ACs.

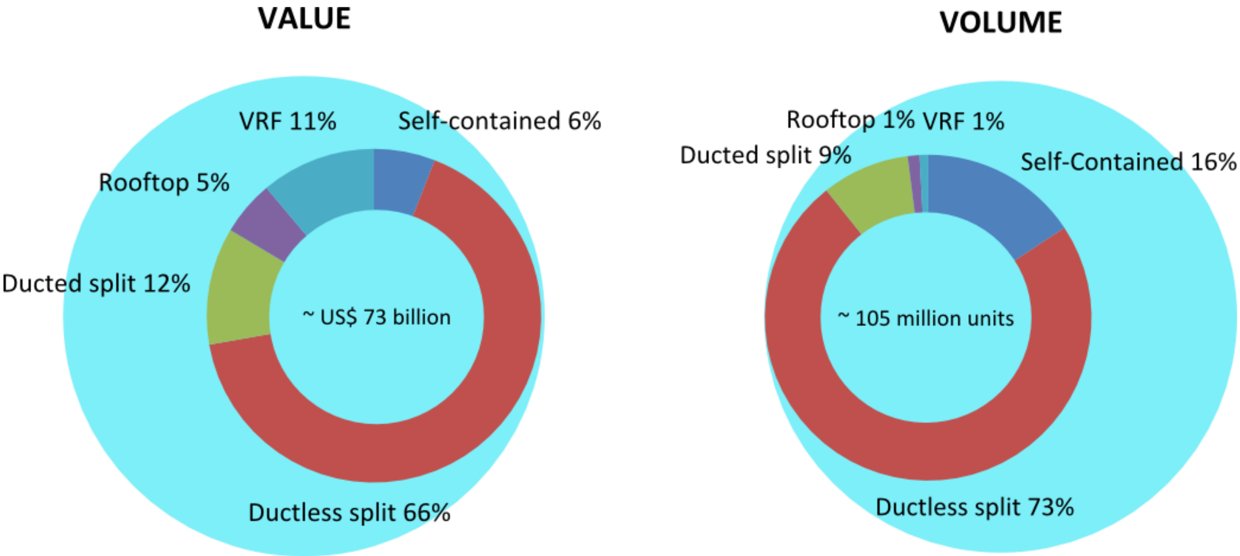


Figure 12: Global demand for residential and commercial UAC systems, divided by appliance system types (2012). (A) shows demand by value in USD and (B) shows the volume in units

The highest proportion of air conditioners (based on the number of units) are UACs with lower cooling capacities (less than 17.5 kW), which are the focus of this chapter. Because of their low market-share, VRFs, rooftop and packaged air conditioners are excluded from the analysis. VRFs will be addressed in the section about AC chillers. VRFs are often installed as an alternative to chillers.
For 2012 this then translates into a market size (without VRF units) of about 100 million units valued at USD 60 billion, regarding ductless, ducted, window-type and movable UACs. Notice that these types of air conditioners will be generalised as UACs in the following and that missing types pointed out above are excluded from the discussion..

Ductless split-systems dominate the market, especially in Asia and Southeast (SE) Asia[44], followed by self-contained devices, such as window-type air conditioners which have significance in Saudi Arabia and the United States. The movable AC market is very small and is not of importance in regions where higher cooling capacity is needed. Ducted split systems are mainly found in the US, where they have a market share of more than 30%. Ductless splits are still missing wider consumer acceptance in the US but they are gaining market share. This stands in sharp contrast to other major markets such as most of the Asian markets, including Japan and China where ductless splits

[44] SE Asia is listed separately because the market has different characteristics to other Asian countries. Here, SE Asian countries are Indonesia, Malaysia, the Philippines, Singapore, Thailand and Vietnam.

are the norm. China is the largest player in the UAC market, dominating both demand and supply (Figure 13 and Figure 14).

The following section contains data on the global demand for UAC – both the current demand and a projection in the future. It will then look at the production side (shown as production capacity) of the UAC market and show the most important manufacturing countries, an overview of global and local manufacturers and market trends for key countries in the UAC market. Production capacity is higher than actual production depending on the degree of capacity utilisation, but actual data on this are extremely difficult to come by. The data shown here on production capacity are therefore to be taken as an upper limit for supply.

4.4.2 Demand

The demand for UAC units is increasing, mainly because of the growing demand in developing and emerging markets with many first time buyers. Not only is the disposable income and standard of living rising in these countries. Factors such as infrastructure improvement, electrification as well as growing distribution networks all contribute to the growing demand for air conditioning as more customers can be reached (HSBC, 2012, 2013). Additional demand appears to be very likely in a warming world due to anthropogenic climate change[45].

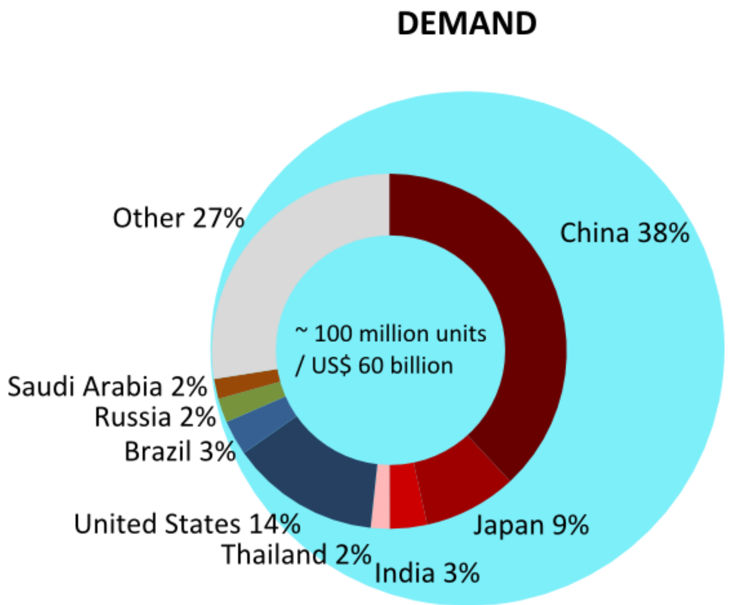


Figure 13: Global demand in 2012 for UAC systems including split ACs, window/through-the-wall units and movable air conditioners

Roughly two-thirds of the global UAC market is located in Asia and SE Asia and the highest growth rates in 2012 were also found in this region. Nonetheless, air conditioner penetration in key markets are still low (e.g., India 4%, Thailand 14%, Indonesia 7%, Vietnam 6%, Philippines 11%). SE Asia experienced a market growth of almost 20% compared to the previous year[46]. Here too, ductless mini-split systems make up the majority of sold units. An exception are the Philippines, where self-contained window units still have a share of 70%[47], which is significantly higher than in India and Taiwan where they contribute 20% and 35% respectively. In Japan and South Korea, mini-

[45] http://e360.yale.edu/feature/cooling_a_warming_planet_a_global_air_conditioning_surge/2550/
[46] http://www.ejarn.com/news.asp?ID=24507
[47] http://www.ejarn.com/news.asp?ID=24513

split systems dominate. China showed a growth in sales of 8% in 2012; with a share of nearly 40%, China is the world's largest UAC market[48].

The US UAC market is the largest in North America and is structured differently than the world average. The demand for ductless mini-split systems is very small (around 3%) in comparison to window units and ducted mini-split systems, which both have a share exceeding 40%. However ductless splits are increasingly accepted as energy and cost efficiency become more important to consumers[49]. Brazil is the largest air conditioning market in South America. As the penetration of air conditioners is still low and there is a large potential consumer base (similar to India)[50], Brazil remains a promising market to look at[51].

Saudi Arabia is the largest air conditioning market in the Middle East where air conditioning is very important due to the climate. Saudi Arabia has the largest share of window units in the world, contributing around 65% to the total 1.8 million air-conditioning units sold in 2012. However, the sales of split units have been picking up here. Egypt is another important market in the Middle East with its strategic positioning toward African markets. Ductless split ACs make up 85% of domestic sales, the remaining 15% are window units. The largest AC market in Africa, with about half a million units, is Nigeria. The distribution between ductless split and window units is comparable to Egypt.

In Europe, Russia is the biggest market followed by Turkey, Italy and Spain. In all European markets, ductless split units are preferred (with a share of 85 to 90%). Movable AC units account for about 7%.

The combined demand of China, Japan, the US, the European countries, Brazil and India accounted for more than 70% of total sales in 2012.

4.4.3 Production

A comparison of Figure 13 and Figure 14 shows the distinctive contrast between annual demand and surplus production capacity. The disparity between current demand and the production capacity somewhat reflects market expectations for a significantly increasing demand in the future. It is also expected that production capacity provides a good picture about manufacturing allocation and possible scale of activity. Manufacturers typically keep excess production capacities to meet the growing sales demand. The excess production capacities indicate the future sales expectations of the companies (Sivak, 2013).

[48] http://www.ejarn.com/news.asp?ID=24477
[49] http://www.ejarn.com/news.asp?ID=24478
[50] http://www.ejarn.com/news.asp?ID=24514
[51] http://www.ejarn.com/news.asp?ID=24522

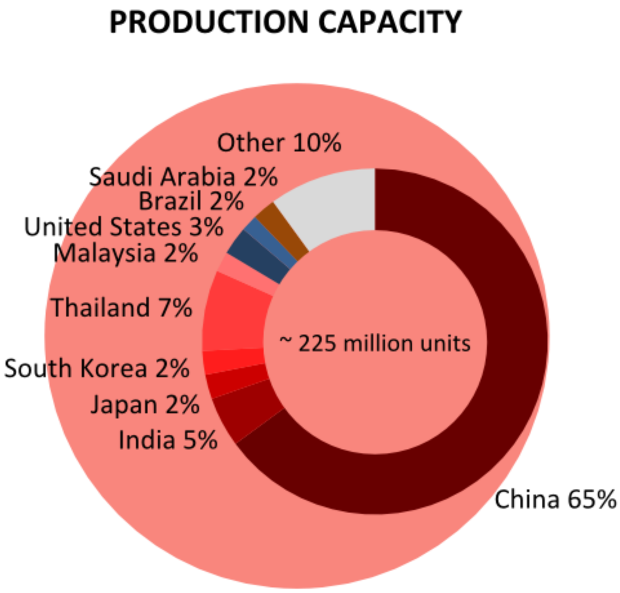


Figure 14: Estimate of global distribution of production capacity for UAC systems in 2012

The most significant UAC-producing countries are all in Asia and SE Asia. Nearly 90% of the world's UAC production capacity is based there. China alone would be capable to manufacture 65% of the world's market or largely over 200,000 units if production capacities were fully utilised (Figure 14). On average, the Chinese air conditioner output in 2012 exceeded 200,000 units produced per day (covering 80% of the global market in 2012) and approximately half of the production went into the domestic market. Another 7% of the world's demand is produced in Thailand, the second largest UAC producer. The vast majority (90%) of Thailand's UACs are currently exported. Figure 15 illustrates market overview plotting demand and country-level production capacities.

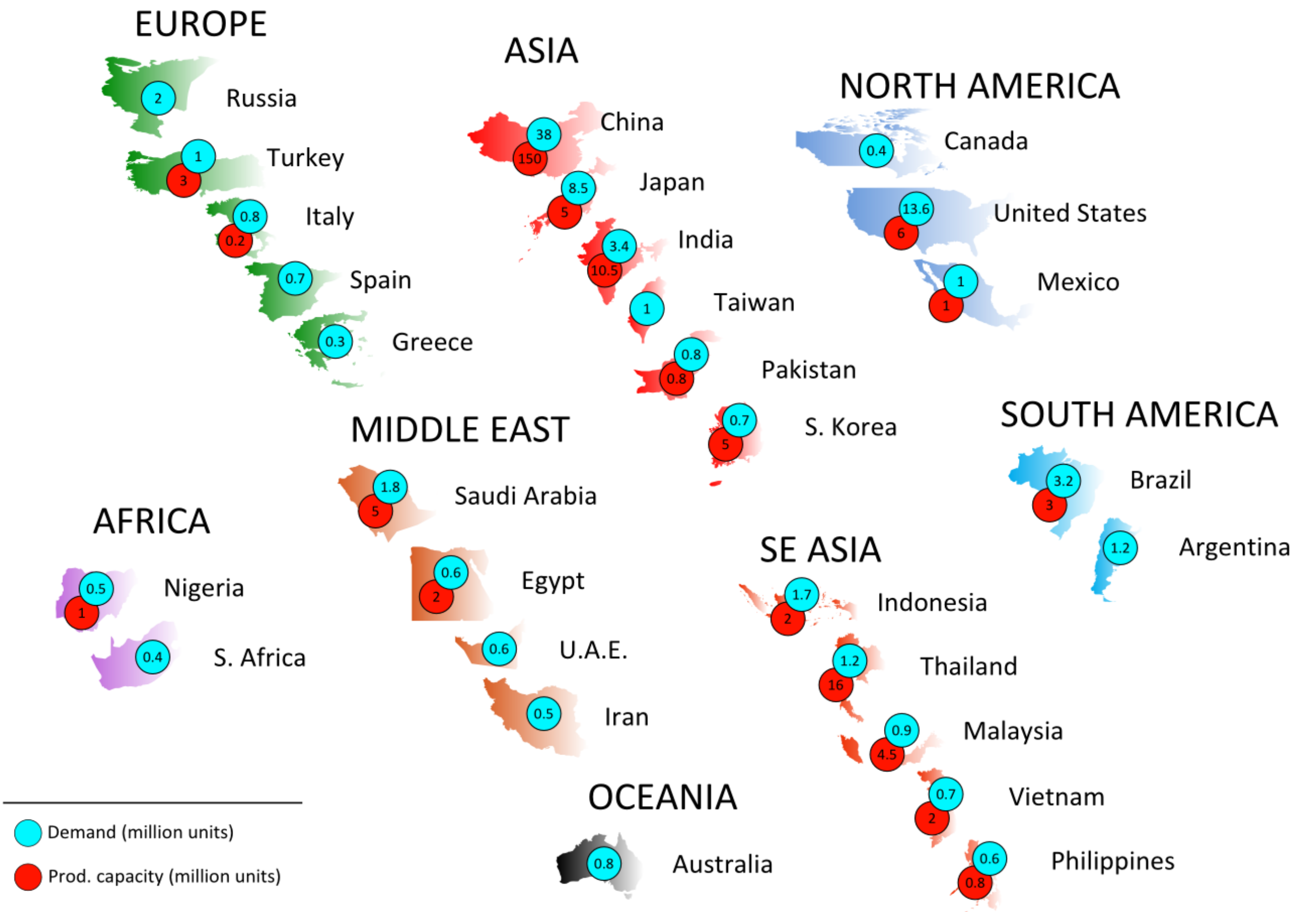


Figure 15: World UAC market and production capacities divided by region

The situation in the main producing countries is as follows:

- **China:** The Chinese market is dominated by Chinese manufacturers. Gree, Midea, Qingdao Haier share two-thirds of domestic sales.
- **India:** Voltas is the manufacturer with the highest market share. Together with South-Korean LG and Samsung as well as Japanese Panasonic they cover almost two-thirds of the market. Godrej and Blue Star are also well-known Indian producers with smaller market shares. Interesting is the near absence of the Chinese manufacturers in the Indian market[52]. This might change in the future because of rising labour wages in China.
- **Japan:** Japan has a developed market, which is dominated by national manufacturers.
- **South Korea:** Similar to Japan, Korean manufacturers dominate the home market.
- **Indonesia:** South Korean and Japanese manufacturers have a strong position in the largest UAC market in SE Asia. Chinese competitors also have local production bases, from which they are also exporting to other ASEAN markets. Domestic producers have a market share of about 5%. Three-quarters of the Indonesian sales are small-capacity mini-splits and 80% of air conditioners are imported.
- **Thailand:** Largely an export hub for Japanese and South-Korean manufacturers, a small number of domestic manufacturers produce for the national market.
- **Vietnam:** Vietnam is a market with significant growth. Because of rising production costs in China and Thailand, Japanese and Korean manufacturers have built manufacturing bases in Vietnam. The trend to shift production capacities to Vietnam may continue as the air conditioning market in Thailand becomes more mature.
- **Malaysia:** Malaysia imports some UACs from China and Thailand, but most of its equipment is produced in the country or imported components are assembled locally.
- **United States:** Ducted air conditioning dominates the US market, distinguishing it from the other ductless-split dominated world markets. The US still is a challenging market for Asian exporters and the popular ducted air conditioners are still manufactured domestically.
- **Brazil:** Almost all known global Japanese, South Korean, US, and Chinese manufacturers have set up factories in Brazil.
- **Turkey:** is Europe's largest UAC-producing country.
- **Saudi Arabia:** Market with local production mainly consisting of foreign manufacturers aligned in joint ventures with local companies.
- **Egypt:** Egypt's unique location as part of the Middle East, Northern Africa and the Mediterranean region gives it a central importance for manufacturers. Whereas a lot of US-American, Korean and Chinese manufacturers have production facilities there, Sharp is the only Japanese company manufacturing in Egypt.
- **Nigeria:** has become especially interesting for Chinese manufacturers. In the recent past, they have set up production facilities (Haier, Shinco) and assembly lines (Chigo). There is a range of technologies specifically designed to meet customer needs in Nigeria, such as automatic voltage switchers for compensating electricity-fluctuations, compressors able to deal with tropical conditions as well as air purifying and mosquito-deterring.

[52] http://www.deloitte.com/view/en_CA/ca/industries/manufacturing/5db1b44d3f0fb110VgnVCM100000ba42f00aRCRD.htm

Figure 16 shows the origin countries of UAC manufacturing companies. Some of these, such as Daikin, Carrier, LG and Haier are operating globally. Others, such as Voltas and Godrej in India are solely domestic producers. Many multinational companies produce in partnerships with local manufacturers or have joint ventures in order to improve their penetration in different markets. Carrier is a good example of such a company. Carrier has global cooperation with Chinese Midea (in China and Egypt) and has established local joint ventures e.g. in Saudi Arabia (SAMCO Carrier). Daikin has also made essential acquisitions in the past to diversify in major world markets.

CHINA	AUX, Changhong, Chigo, Gree, Haier, Hisense, Midea, Shinco, TCL
JAPAN	Daikin, Fujitsu General, Hitachi, MHI, Mitsubishi Electric, Panasonic, Sharp, Toshiba
INDIA	Blue Star, Godrej, Videocon, Voltas
S. KOREA	LG, Samsung
THAILAND	Bitwise, Eminent, Sajo Denki, Unifab
MALAYSIA	O.Y.L. (Daikin)
VIETNAM	Funiki, Reetech
TURKEY	Airfel (Daikin), Alarko (Carrier), Arcilek (LG), Demir Dökum (York)
ITALY	Armec, De Longhi, Olimpia Splendid
EGYPT	El-Araby, Miraco (Midea, Carrier), Unionaire
SAUDI ARABIA	Alessa, Al-Salem (York), H.G. Ibrahim Shaker (LG), Petra, SAMCO-Carrier, ZAMIL
BRAZIL	Multibras
UNITED STATES	Carrier, Friedrich, Goodman (Daikin), Lennox, Rheem/Ruud, Trane, Whirlpool, York

Figure 16: Local manufacturers in key UAC-producing countries. Note: Some may act on multi-national level or belong to other multi-nationals as part of their global operations

Figure 17 shows the countries of origin and the countries in which UACs are being produced for manufacturers acting on the multi-national level. Asian manufacturers clearly dominate the world stage and Asia and SE Asia are the major manufacturing regions. Chinese manufacturers mainly produce within their own country whereas Japanese and South Korean companies have most of their production outsourced to other Asian countries. Chinese and Korean manufacturers have started producing in Africa. US manufacturers are only slowly penetrating Asian/SE Asian UAC markets but are very active in all other regions of the world. European companies mainly produce for the European markets.

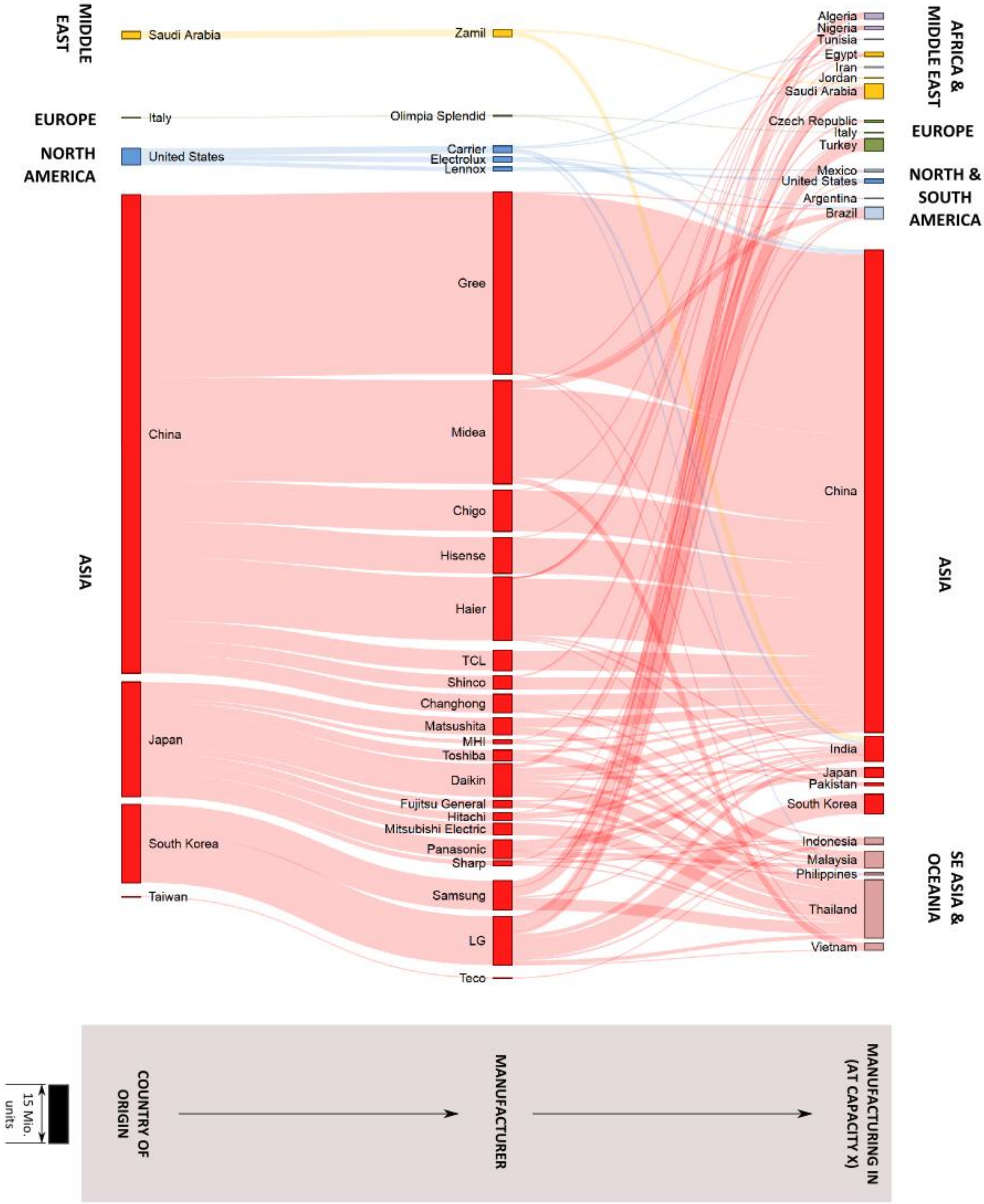


Figure 17: Manufacturing activity of multi-national manufacturers[53]. The figure only shows operational activity and allocated production capacities. The precise type of operation (e.g. fully developed production facilities or simple assembly lines) cannot be specified.

4.4.1 Future demand and stock

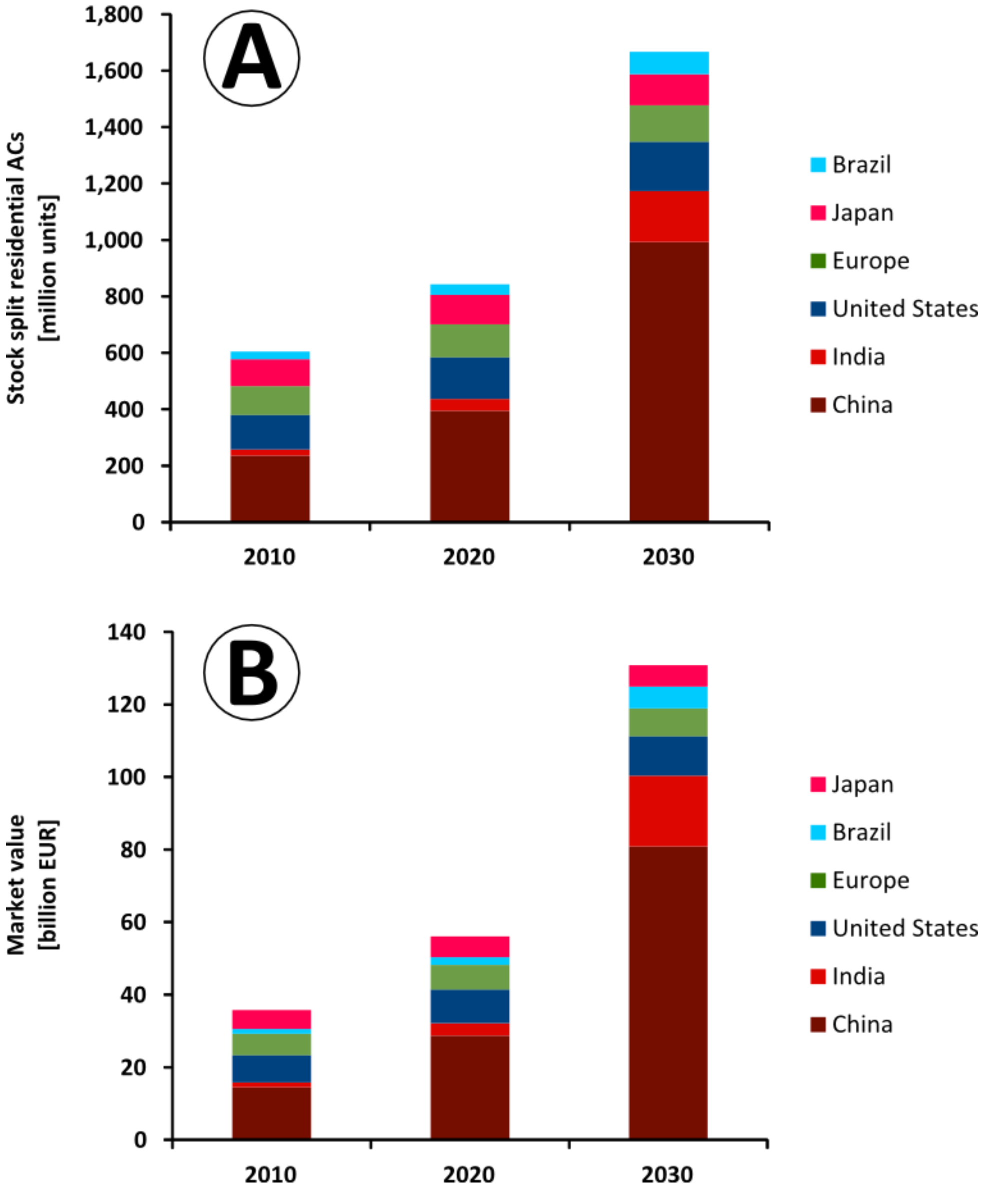


Figure 18: Modelled future stock of residential split air conditioners for 2010, 2020, 2030 (A) and estimated market value for the top-6 countries (B)

As expected, the total stock of residential split air conditioners is projected to increase, whereby the increase between 2020 and 2030 is much stronger that the increase that is observed from 2010 to 2020 (Figure 18A). This trend is reflected by the market, which shows a similar pattern of increase (Figure 18B). The model results further

[53] Some manufacturers especially in the US might be significantly underrepresented as limited information is publically available on their production capacities and sales.

show that the stock from the top-6 countries, which make up 80% of the global[54] stock, will grow from currently 600 to nearly 1.7 billion units. The corresponding market is projected to increase from around 36 billion Euros in 2010 to more than 130 billion Euros by 2030 (Figure 18B).

Various different growth trends are observed depending on the country and region (Figure 18A). While the Asian countries (red colours) show a strong increase in both stock and market values, except for Japan, there is a moderate increase and stagnation seen in the US and Europe[55]. Generally this difference is explained by different GDP growth, which is expected to increase exponentially for some Asian countries. A stagnation of stock and market is observed for the US because the AC market there is already highly saturated. Stock and market in Europe show a slight increase only. The projected future increase in Europe may be underestimated, because higher temperature levels due to climate change are expected to boost the air conditioning market in Europe. However, this parameter was not included in the modelling approach.

Again, China is the most dominant country with regard to stock and market value. The country represents half of the stock from the top-6 countries by 2030. India is the second most important country, following behind the Chinese development by several years.

4.4.2 Global GHG emissions and reduction potential

Total emissions mirror the stock in the country, as the emissions caused by operating an AC unit largely contribute to the overall emissions. Therefore, high stock numbers will cause high emissions. Consequently, the emission trend (Figure 19A) follows the stock trend (Figure 18A), with China and India showing high growth rates, in contrast to the US and Europe. China's emissions from split residential air conditioners are already double the emissions from the US and Europe. India's emissions are currently below the emissions from the US and Europe, but will supersede US emissions between 2025 and 2030 (Figure 19A). Again, China plays a special role as the expected future emissions are in the magnitude of more than 1600 Mt CO_2eq by 2030. The plotted countries in Figure 19A make up 80% of the global emissions from split residential air conditioners.

The high mitigation potential within this subsector can be seen in Figure 19B[56]. The underlying model assumptions account for the replacement of the refrigerant and an improved appliance energy efficiency[57]. Emissions can be reduced rapidly as new green technology is phased in. Highest emission reductions are found in countries with significant stocks and total emissions. The emission reduction potential in all counties ranges between 60 and 70% when state-of-the-art technology is introduced. In China, more than 1000 Mt CO_2eq could be reduced annually by 2030.

[54] Global refers to the most important 99 countries for which the comprehensive stock modelling was performed. A list of these countries can be found in the annex

[55] Europe figures consist of data for Germany, United Kingdom, France and Italy. These are currently the most important countries in Europe.

[56] The reduction potential is visible from 2010 onwards as penetration rates of green technology have been interpolated between 2010 and 2015.

[57] A full description of the mitigation scenario can be found in module 5 of the technical handbook "NAMAs in the refrigeration, air conditioning and foam sectors" (Proklima, 2013).

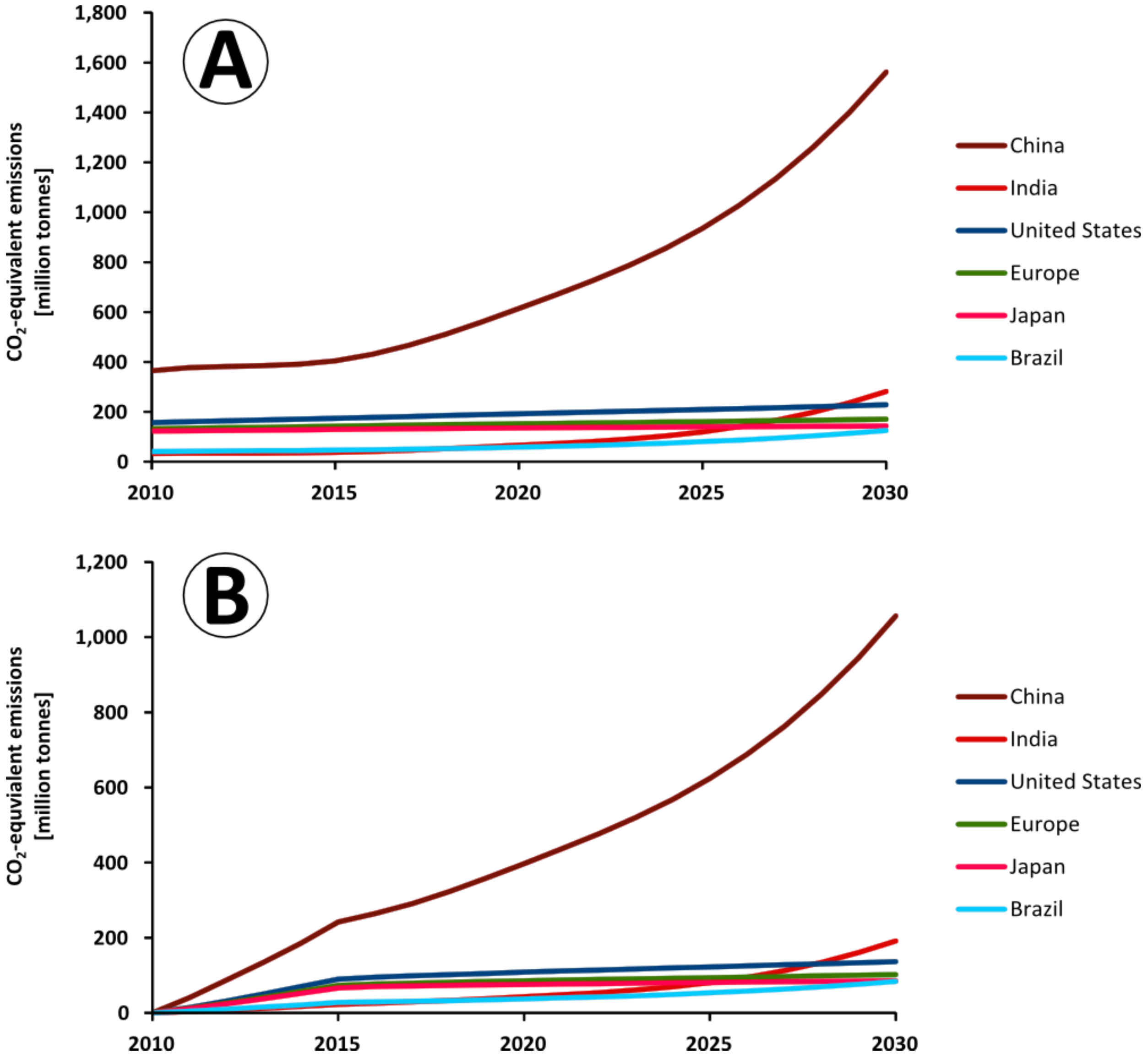


Figure 19: Projected total (direct and indirect) emissions from residential split air conditioners for the top-6 countries as calculated by a vintage bottom-up stock model (A). Key determining factors are stock and sales figures. The upper graph (A) shows the BAU scenario, while the bottom graph (B) shows the mitigation potential.

4.4.3 Market situation and technology options in key-focus markets (China, India and Brazil)

New technology trends in the market

The main new technology trend in the UAC market is the inverter technology. Inverter technologies are regularly used in Japanese and Oceania ductless split-systems and have quickly risen to a significant share in China. The penetration rate of inverter technologies to other markets such as Latin and Northern America remains slow (Figure 20) although more than 30% of 2012 UAC sales were inverter devices. Especially the US market has been largely inert to adopting inverter UACs for a long time as ductless splits only very slowly become interesting to consumers. However, with improved energy efficiency regulations coming into place, inverter UACs are expected to find more consumer attraction in the US market. Rising interest in inverters shows that the market may eventually shift rapidly towards the integration of these features.

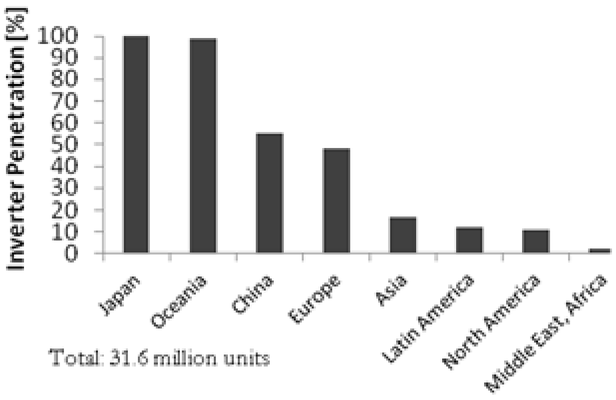


Figure 20: Penetration of inverter air-conditioning technology by region.[58]

4.4.3.1 China

Market Situation. In 2012, the China's market for residential air conditioning was more than 10 times larger by sales than the Indian and Brazilian markets. Penetration of residential air-conditioning closes in on 95% in the largest cities[59], and the buying trend now transits from first-time buyers to replacing old equipment. First-time buyer demand will gradually shift to rural markets as incomes rise. Only 23% of households in rural areas own air-conditioning devices so far. Rural areas therefore provide large potential for air conditioner sales.

Inverter Technology. Over the past few years, inverter air conditioners, using R410A as refrigerant, have become more popular and environmental awareness has increased in China. From 2009 to 2012 the market share of inverter devices has taken a leap from 10% to over 50%. However, the use of non-inverter air conditioners will likely not be abandoned too soon, as they are well-positioned in the lower price range, which meets the needs of the consumers in rural market where disposable incomes are lower. Additionally, because China is the major global production hub for air conditioners, it will continue to manufacture non-inverter devices in order to satisfy the demand of importing countries such as the US where demand for inverter air-conditioning is very low.

4.4.3.2 India

Market Situation. Sales of UAC in the Indian market accounted for more than 3.4 million units in 2012. The share of split-systems is continuously increasing, overtaking that of self-contained window-type units, and is currently estimated to be around 80%. Because the Indian market is still in development and consumers are very price sensitive (i.e. small changes will have a high impact on demand), there is high competition between split and window ACs and prices tend to be significantly lower than in other markets.

The massive devaluation of the Indian Rupee since the second half of 2012 led to manufacturers having to raise prices as two-thirds of the air-conditioning components are imported. Because of this, localised production could become more competitive in India.

For now, room air conditioners have a country-wide penetration of 3 to 4%, of which 40% are installed in urban areas. Hence there is still large potential for growth (Sharma et al., 2012) and annual growth rates of 13.5% until 2017 are expected[60]. Since room air conditioner appliances are not common home appliances at the moment, India also has the opportunity to "leapfrog" the usage of high-GWP HFC refrigerants and transition directly to natural-based solutions. Currently almost all locally manufactured and sold room air conditioners are equipped with HCFC-22, although importers have turned to R410A.

[58] http://www.ejarn.com/news.asp?id=25298&classid=10
[59] http://www.ejarn.com/news.asp?id=22767&classid=17
[60] http://www.researchandmarkets.com/reports/2141576/india_air_conditioners_market_forecast_and

Inverter Technology. The penetration rate of inverter UACs in India is still only at 6% people still have little knowledge about inverters.

4.4.3.3 Brazil

Market Situation. Domestic sales of residential air conditioners in 2012 were in the range of 3.2 million units and therefore comparable to India in market size. Growth had similarly been expected to be higher. Even though Brazil has a large population of 200 million people and a growing middle class, the air-conditioner penetration is still low. The largest UAC market in the southern hemisphere therefore still has potential for significant growth in AC units. The trend of adopting VRF- and inverter-friendly R410A instead of HCFC-22 is increasing. Currently, split systems are gaining ground over self-contained window-type air conditioners even though prices are increasing due to rising industrial taxes and currency devaluation of the Real. Similar to the situation in India, localisation of production remains a key issue in a country with high import tariffs.

Inverter Technology. Inverter devices contribute about 7% of all units as Japanese companies have captured notable market share. However, the market uptake remains challenging.

4.5 Conclusion

The UAC subsector has the highest predicted growth and emissions of all the RAC sectors.

China plays an important role in the UAC subsector as it has the highest demand for AC units as well as being the biggest producer. In recent years, China has set higher MEPS and subsidised energy efficient ACs, leading to distinctly higher energy efficiency in the country's AC stock. China alone is able to provide way more than half of the world's UAC demand and a few key Chinese producers could become highly influential in changing the UAC market. All leading Chinese suppliers are for example already able to produce highly energy efficient equipment with HC-290 as refrigerant. The low amount of refrigerant in most UAC units makes hydrocarbons a safe choice for home appliances.

The predicted rising demand is also related to many developing countries being far from reaching their full saturation with UAC. Apart from few countries, such as Thailand, there is little production in these countries, which therefore have to rely on imports. More and more developing countries have recently introduced MEPS or are in the process of introducing MEPS and labels in order to protect themselves against being the dumping ground for energy-intensive units. More stringent MEPS that are at least as demanding as the Chinese standards will drive the development towards more energy efficient appliances in the long term. Higher MEPS could be a chance for UAC manufacturers in Thailand to gain a competitive advantage in the market, as they are already producing for the Japanese market with its very high energy-efficiency requirements. UAC demand in India will grow strongly in the future. Energy demand from UAC units will put an additional burden on the already tight electricity supply situations. India will greatly benefit in the future by further heightening MEPS targets. As India will be the next biggest emerging market outside of China, Indian companies will play a much more important role in the future. Energy-efficient UACs with inverter technology and natural refrigerants are not as established yet in Indian companies as they are in Chinese companies but their introduction could lead to very high emission savings in the future.

Mandatory MEPS for the majority of UAC consuming countries could lead to a shift to higher energy efficiency globally. There are now good practice MEPS examples from developing countries such as Ghana and India. Raising public awareness about MEPS is important for the successful implication and this could be supported by NGOs. The introduction of MEPS will significantly increase if there is broad stakeholder support (CLASP, 2002). NGOs can also support countries with the implementation of MEPS. China has shown that subsidies for energy efficient models can be very successful to catalyse the introduction of highly energy efficient appliances until the production has reached sufficiently high economies of scale. Often, for the economy the costs of such catalysing introduction programmes will be quickly paid back as higher investments in electricity generation, especially for additional costly peak power plants can be avoided. The MLF can accelerate the introduction of green cooling technologies by only financing production conversions from HCFC-22 to models where energy efficiency and natural refrigerants are considered.

5 Mobile air conditioning (MAC)

5.1 Subsector characterisation

5.1.1 Overview

Vehicles can heat up significantly in hot weather or under direct influence from sunlight. MAC systems are installed in cars to keep drivers comfortable and safe. This is the reason why the capacity of MACs for passenger cars lies in the range of around 5 kW (IPPC/TEAP, 2005).

For conventional cars, the compressor in MACs is connected to the car engine via a belt and there is direct transfer of mechanical power. Fans and controls are powered by electricity.

It is estimated that 9% of greenhouse gas emissions from cars are due to direct and indirect emissions from MAC use (US EPA, 2010). In 2006, 20 % of the global refrigerant emissions were from MAC systems in passenger cars (UNEP RTOC, 2011). These direct emissions result from leakage during manufacturing, operation, servicing, repair and at end-of-life. Indirect emissions are due to increased fuel consumption due to MAC operation.

After the phase-out of CFCs and HCFCs under the Montreal Protocol, the refrigerant used in MAC is predominantly HFC-134a (see also Figure 4 in chapter 2). However, due to its high GWP of 1,430, the use of HFC-134a increasingly faces restrictions around the world. Few car manufacturers have started to use u-HFC-1234yf in Europe and only in new car models since it became commercially available in late 2012. Hydrocarbons are sometimes used in the aftermarket in some countries to avoid the more expensive HFC-134a. The charge size is usually smaller than 1 kg with an average of 600 g (Schwarz et al., 2011).

End-users of MAC systems are almost exclusively car original equipment manufacturers (OEMs).

5.1.2 Energy efficiency trends

There are few numbers on the energy efficiency of MACs for several reasons. MACs are custom-made for car manufacturers and installed during the production of cars. Car manufacturers do not usually publish the COP of MACs and the only numbers come from estimating additional fuel consumption during driving. Scientific publications often consider theoretical aspects or try to model different conditions or components. Measured COPs or actual fuel consumption have been shown to be different to theoretical expectations in the past (Hrnjak, 2010).

The additional consumption of fuel of a MAC depends on many different factors: Besides the ambient temperatures and humidity, the rotation speed of the motor, the car model and refrigerant type all play a role.

Additional fuel consumption in Europe and the US was measured to be between 3 and 18% depending on ambient temperatures, driving speed, humidity etc. with a yearly average of 5.4% (Weilenmann et al., 2010), but around 20% in China and India, mainly because of the climate (NRDC et al., 2013). Because the additional fuel consumption stays similar for all cars, its percentage is higher in cars with higher efficiency (Johnson, 2002).

A little less than 10 years ago, the typical COP of a MAC at 35°C was in the range of 0.9 to 1.6 (IPCC/TEAP, 2005). Over the last 10 years, it has become considerably higher. The IMAC 30/50 project (Improved Mobile Air Conditioning) project from 2004 to 2007 had pledged to reduce energy need by 30% and reached their goal easily using commercially available technology[61]. Depending on motor speed, ambient temperature, refrigerant and technical set-up, COPs in scientific papers are given in the range of 1.6 up to 4.0 (Brown et al., 2002; Kim et al., 2009; Lee and Jung, 2012; Hrnjak, 2010). This does not mean that there are systems commercially available that have COPs in this range. A comparison concerning COPs of HFC-134a and CO_2 systems is inconclusive. Based on simulations, some authors see higher efficiencies for HFC-134a (Brown et al., 2002), but experimental data show equal or higher COPs for CO_2 at ambient temperatures below 35°C (Kim, 2004; Tamura et al., 2005; Hrnjak, 2010; TEAP, 2013). The performance of u-HFC-1234yf is worse than that of HFC-134a (Lee et al., 2011; Zilio et al., 2011). Competition between different refrigerants has led to an increase in COP in all refrigerant systems over time that is higher than the difference in COP between the refrigerant systems (Hrnjak, 2010).

5.2 International and national regulations

The EU MAC directive has been introduced to drastically reduce direct emissions of refrigerants. It restricts refrigerant use to those with a GWP of less than 150, thereby banning HFC-134a, which was globally used until now. This rule applies for new type-approvals from 2011 and for all new cars from 2017. Nearly all Tier 1 multi-national MAC suppliers already have developed systems with low-GWP refrigerants. The dominant options here are u-HFCs and CO_2. European manufactures will be forced to implement low-GWP refrigerant systems in the market by 2017. As a result, car manufacturers initially agreed to use the specifically developed u-HFC-1234yf. After tests by Daimler showed u-HFC-1234yf to be ignited in crash testing, other German manufacturers, including the VW group and BMW joined Daimler's announcement to opt for CO_2. Developments with CO_2 MAC systems were already going on with nearly all Tier 1 MAC suppliers since the early to mid-2000s, but were stopped after the u-HFC-1234yf agreement. After the German car manufacturers opted for CO_2 systems, developments were newly started.

In the US, only refrigerants approved by the EPA's SNAP Program can be used. In the low-GWP category for mobile air conditioning HFC-152a, CO_2, and u-HFC-1234yf, are SNAP-approved. California's proposed Low Emissions Vehicle regulation (LEV III) requires cars to use refrigerants with a GWP of 150 or lower. Also, the US CAFE (Corporate Average Fuel Economy) standards set minimum efficiency standards for cars, mainly based on fuel usage during normal driving conditions. Recently, these standards include a credit system that gives points if a car has an efficient MAC system or uses a low-GWP refrigerant (US EPA, 2010).

Because of the homogeneous global MAC market, there is a tendency that car manufacturers opt for MAC units fulfilling the most stringent environmental and safety restrictions in the world, which come from the EU and the US (NRDC et al., 2013).

5.3 Scope of Improvement

5.3.1 Alternative Technologies - refrigerants

The following, refrigerant-related changes will lead to savings in direct emissions:

Switch to alternative refrigerant

- Several MAC suppliers have reportedly reached implementation readiness for CO_2 systems (own interviews IAA, TEAP 2013). Key component developments were ongoing with regard to internal heat exchangers, external control measures, micro-channel gas coolers and evaporators. Because CO_2 refrigerant requires higher pressures, component walls have to be reinforced. Higher pressures make the system smaller, but maybe slightly heavier. Initially, upfront costs are estimated to be higher in

[61] http://www.epa.gov/cpd/mac/

comparison to conventional systems (Schwarz et al., 2011) and the system needs to be significantly altered compared to HFC-134a. However, because of similar or less material requirements and the extremely low cost of the CO_2 refrigerant, this is likely to decrease rapidly. CO_2 is non-flammable, non-toxic, readily available, cheap and efficient. It is nontoxic, but as higher partial pressure (from 1%) in the driver's cabin could lead to drowsiness, special care to prevent leaks into the cabin has to be taken. The different design means that it is not technically possible to illegally use HFC-134a as a drop-in in CO_2 systems in the aftermarket. Both Daimler and VW have announced publicly to install CO_2 MAC in their new car models as soon as the systems are available.

- U-HFC-1234yf could be used as a 'drop-in' in existing HFC-134a systems or would only require small system changes. Without adjustments, the cooling capacity and performance are lower than for HFC-134a (Lee and Jung, 2012; Zilio et al., 2011). U-HFC-1234yf is flammable and produces the highly corrosive and therefore dangerous HF when it burns. Particularly the flammable nature of u-HFC-1234yf has triggered the German manufacturers, Daimler, BMW and VW/Audi to drop the use of u-HFC-1234yf due to the inherent safety risk of this refrigerant. For the Chinese and Indian markets, u-HFC-1234yf is considered very expensive and there is little access to it, making a global rapid change from HFC-134a unlikely (NRDC et al. (2013).

Challenges: The servicing sector would need additional technician training and equipment at service stations. This is true for both CO_2 as well as u-HFC-1234yf systems.

Leak reduction

- Leaks from MAC are very high, reaching 10-15% annually in developed countries (IPPC/TEAP, 2005). In developing countries this is closer to 20% on average, reaching up to 40% depending on servicing and road conditions (UNEP, 2013). This is due to the design where refrigerant is led through hoses that are prone to leakage, the compressor is open because of its connection to the motor and vibrations during driving will continuously loosen connections (Hrnjak, 2010). Even though average leakage has been significantly reduced over the last years from 40% in the 1990s (Hrnjak, 2010), the accumulated effect of millions of cars is still considerable. HFC-134a is widely available on the internet and this leads to car owners doing their own servicing – which has a high potential for release of refrigerant.

Challenges: Natural refrigerant ammonia has not been considered an option for MAC - because of its toxic and corrosive nature it poses a harm to people in the driver's cabin and components in the motor compartment. Even though HCs have shown very good efficiency especially in high ambient temperature environments and are used in the aftermarket, they are currently not the favoured option because of their flammability.

5.3.2 Energy efficiency

CO_2 as refrigerant in MAC is more efficient for ambient temperatures below 35°C whilst driving and below 25°C when the car is idle (Hrnjak, 2010). Because the CO_2 system requires higher refrigerant pressures, it is smaller. This is important in cars with restricted size. Additionally, a CO_2 system allows for heating in a reverse cycle. This becomes important because the generated motor heat in some efficient cars is too low for heating in cold winter months.

In spite of known leakage rates for MAC systems, these refrigerant emissions so far have not been accounted for in the CO_2-emissions calculations for cars. In 2009, the US EPA published the Green MAC LCCP, a tool to calculate the so-called life cycle climate performance, taking into account both direct and indirect emissions.[62]

[62] http://www.epa.gov/cpd/mac/compare.htm

Table 11: Energy efficiency measures in MAC

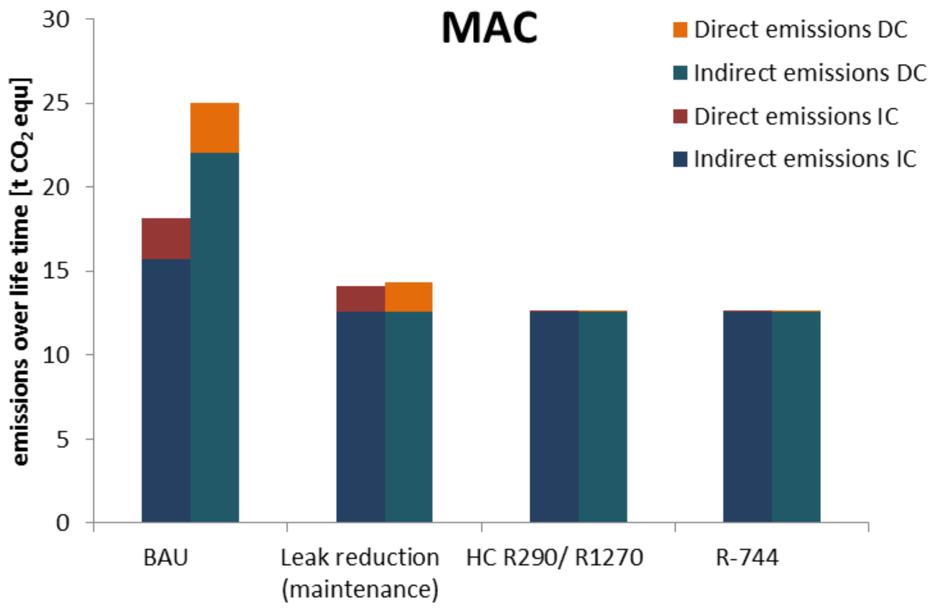
	Measure	Improvement COP
Cycle improvements	Ejector High side pressure controller	15% (Lee, 2011)
Parasitic losses		
Cycle modifications	CO_2 refrigerant, two-stage compressor	20% (Janotkova and Pavelek, 2006)
Change in use	Energy management, heat reflecting windows, parking in the shade	2-4% of total fuel consumption (Glass for Europe, 2011).

5.3.3 Reducing cooling needs

The energy needed for cooling cars can be reduced considerably in cars by reducing the heat load. The initial cool down requires the most energy. The temperature of the car cabin can be as high as 60°C after standing in the sun. A reduction of this heat load is possible by behavioural changes such as parking in the shadow or buying a white instead of a dark coloured car[63]. Another option is to install special heat rejecting windows. This could reduce the heat load by up to 10°C[64].

5.3.4 CO_2 emissions over life time

BAU emissions in developing countries are again higher than in industrialised countries. This is due to lower COPs in developing countries in often older cars. Leakage rates can also be affected by temperature and are higher in hot countries (LCCP-Model). As many developing countries have hotter climates, this is again included in the calculations. Additionally, there is no collection system for used refrigerants in many developing countries, so that end-of-life emissions are higher (Clodic et al., 2010). It was assumed that the same energy efficiency standards can be reached in developing countries over time.



[63] R.Wecker, a2-solar : Potentials of Solar Systems in Vehicles for Air Conditioning. "PRO KLIMA - Zukunft der Autoklimaanlage" 4/12/2013.
[64] V.Fourcade, Glass for Europe : Solar control glazing to curb heat load and air-conditioning fuel consumption. "PRO KLIMA - Zukunft der Autoklimaanlage" 4/12/2013.

Figure 21: Lifetime CO_2 emissions in mobile air conditioning systems for the business as usual and several emission reduction options in industrialised (IC) and developing countries (DC). An average value has been applied for IC and DC as there are significant differences within those country groups.)

5.4 Production and demand

5.4.1 Overview

The original equipment manufacturers (OEMs) or automobile manufacturers largely direct the world MAC market. Automobile manufacturers deliver the specifications for system (tier-1) suppliers to develop and manufacture tailor-made MAC systems for their car-models. The whole market structure is globalised as multi-national car OEMs have established production facilities and sales networks all over the world in order to be well-positioned in different markets. The supply chain has aligned along these globalised structures and system suppliers manage their own supply network (Meißner and Jürgens, 2007).

Major global MAC system suppliers for passenger cars are DENSO Corp. (Japan), Valeo SA (France), Halla (Korea), Visteon (USA) Climate Controls, DELPHI Automotive (USA), Mahle-Behr GmbH & Co. KG (Germany), Calsonic Kansei (Japan), and Keihin Corp. (Japan). Their market shares are illustrated in Figure 22.

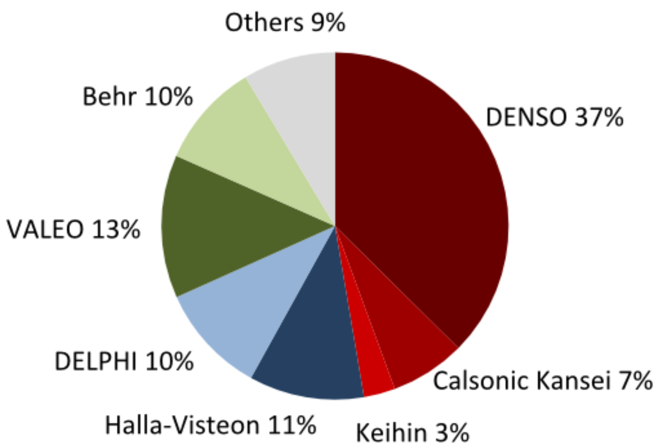
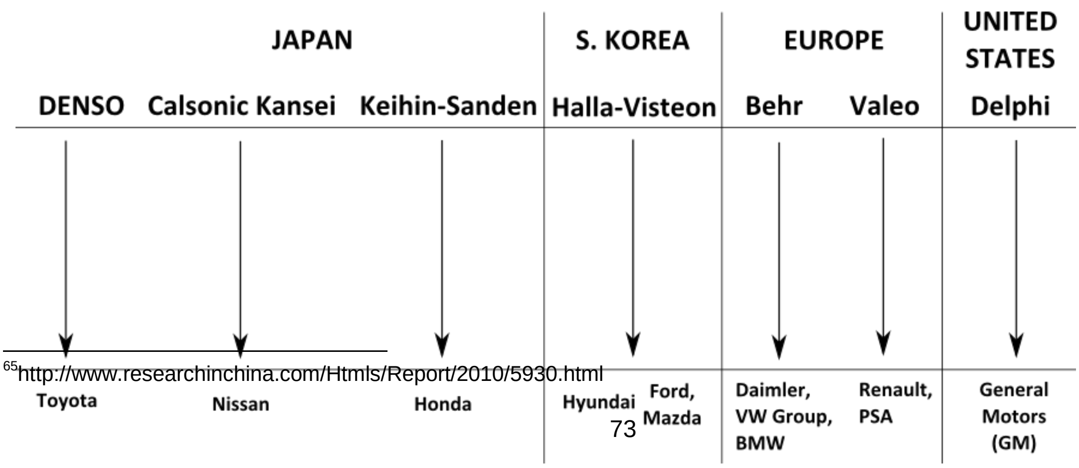


Figure 22: Global market share of major MAC suppliers by shipment (2009)[65]

Most OEMs have a varied MAC-supplier portfolio although many rely on strong ties to specific suppliers. Good examples are the association of DELPHI with General Motors, which emerged in 1999, or DENSO, being traditionally associated with Toyota. Figure 7 illustrates the preferential relationships between dominant system suppliers and specific OEMs.



[65] http://www.researchinchina.com/Htmls/Report/2010/5930.html

Figure 23: MAC suppliers and affiliations to prominent OEMs. PSA stands for PSA Peugeot-Citroën.

The global organisation of the automotive suppliers is highly specialised and competitive, which is in the interest of automobile OEMs. MAC system suppliers produce complete air conditioning devices with control systems for cars. Production of MAC systems is a mass market, which has now also reached lower-class cars and this leads to strong price pressure among MAC suppliers. Upper and premium class automobiles beyond the mass market represent the segment where product diversification and innovation is most likely to take place[66]. This seems plausible under the assumption that OEMs achieve the best trade-off charging people higher prices for high-value equipment rather than providing new technologies to customers who want to pay the same price (Dvir and Strasser 2013).

5.4.2 Demand

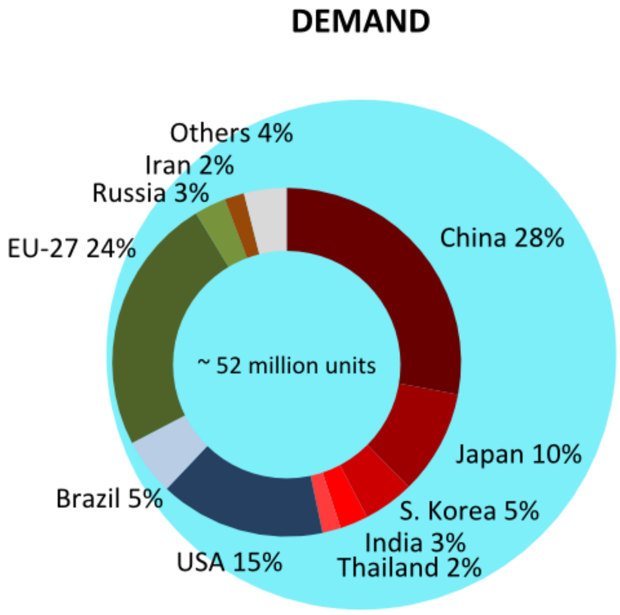


Figure 24: Demand (domestic sales) estimates and global distribution of MAC-equipped automobiles in 2012[67]

Together, China, EU-27, USA, Japan, Brazil, India, and Russia make up 80% of total annual MAC-equipped car MAC sales (Figure 24). Integration of MAC systems in cars is very common in developed countries and increasing in developing countries. Mass production of MAC systems already began in the early 1960s in the US followed by Japan and other Asian countries in the 1970s. Massive rise of car MAC in Western Europe set in from the early 1990s.The approximate rate of MAC-systems in newly-manufactured cars is close to 99% in North America and Japan, about 90% in Western Europe (ca. 80% in overall Europe) and Asia. MAC penetration in China has reached a rate of more than 94% in 2010. The number of MAC containing cars is on average approaching 60% in the rest of the world (Rave and Goetzke, 2011; Clodic et al., 2005; GREEN-MAC-LCCP, 2007).

[66] IAA13 personal communications
[67] http://www.oica.net/category/sales-statistics/

5.4.3 Production

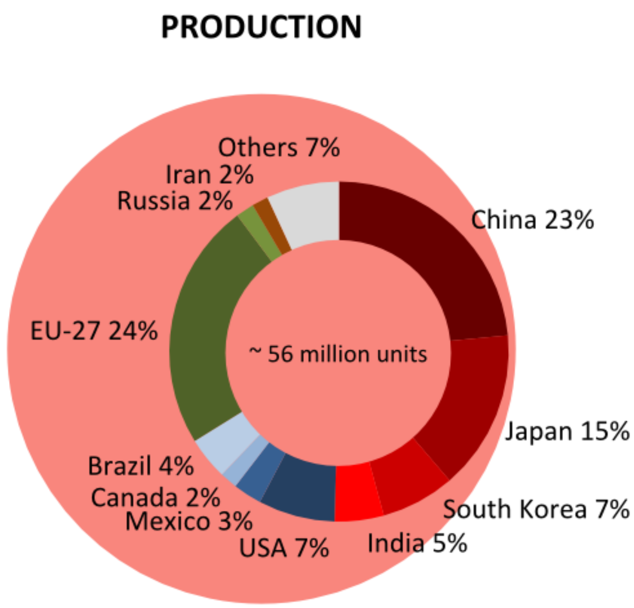


Figure 25: Global distribution estimate of MAC-equipped automobile production in 2012[68]

China, the EU-27 countries, Japan, South Korea, the United States and India, make up 80% of the world's passenger car production equipped with MAC systems (Figure 25). Production is still predominantly situated in industrialised countries such as Germany, Japan, South Korea and the US. However, the relative share of developing countries is rapidly increasing, especially with the emergence of China as a leading car manufacturing country by volume (see Figure 26 for details).

Figure 26 and Figure 27 show the countries of origin of the main car companies and brands and the key car and MAC producing countries (the companies shown here comprise over 90% of the market). Most companies are present in all regions and in many different countries. The network of the supply chain works best for OEMs when it is short and efficient. Thus one can assume that MAC suppliers work in close cooperation with car OEMs in order to guarantee "just-in-time" delivery. DENSO, automotive supplier for Toyota in the United States, for instance, has production facilities in the United States as well as Mexico and Canada to manage efficient delivery.[69,70]

With the growth of the Latin American economies, German manufacturers moved to produce in Latin America, with their main production sites in Argentina and Brazil. German car manufacturing VW Group, as well as Japanese and US car makers have plants in Mexico. Behr is one of the MAC producers that provides air conditioning for VW, Mercedes Benz and Fiat in Brazil. DENSO also has production facilities for manufacturing car air conditioners there[71].

Even though the scale of production in China is very high, it has yet to become a major car exporting country. The automotive industry is split in many small companies, but is intended to be merged to fewer players in order to enable faster access to overseas markets (APCO worldwide, 2010). Foreign companies are only allowed to produce cars in China through joint ventures. Examples for car manufacturers are Beijing Daimler, Nanjing Fiat or Beijing

[68]http://www.oica.net/category/production-statistics/
[69] http://www.autonews.com/article/20130115/OEM10/130119885/denso-will-invest-$750-million-in-u.s.-expansion
[70] http://www.ejarn.com/news.asp?id=18060&classid=9
[71] http://www.globaldenso.com/en/newsreleases/100316-01.html

Hyundai. MAC producing joint ventures are Shanghai DELPHI Auto Air Conditioning System, Guangzhou DENSO and Dongfeng-Behr Therm. Syst. German suppliers, such as Behr tend to ship parts to German manufacturers in China for quality assurance (APCO worldwide, 2010). Japanese and Korean OEMs rely on tier-1 suppliers from their respective countries, either through import or local production (APCO worldwide, 2010).

The African and Middle Eastern markets are dominated by companies from Europe and Asia. US-American companies play no important role.

Japanese and Korean brands have the largest share of production in Asia and SE Asia. The Japanese market remains a challenge for western suppliers because the ties among the Japanese supply chain are extremely hard to breach[72].

 CHINA	Brilliance, BYD, Changan, Chery, Dongfeng Motor, FAW, Geely, Great Wall, SAIC
 JAPAN	Fuji, Honda, Mazda, Mitsubishi, Nissan, Suzuki, Toyota
 INDIA	Mahindra, Tata Motors
 S. KOREA	Hyundai-Kia Group
 MALAYSIA	Proton
 GERMANY	BMW, Daimler, Porsche, VW Group
 FRANCE	PSA (Peugeot-Citroen), Renault
 ITALY	Fiat
 RUSSIA	Avtovaz
 UNITED STATES	Chrysler, Ford, General Motors (GM)

[72] IAA13, personal communications

Figure 26: Manufacturers of passenger cars with MAC systems in key car producing-countries. Some of them act on multi-national level (see next figure)

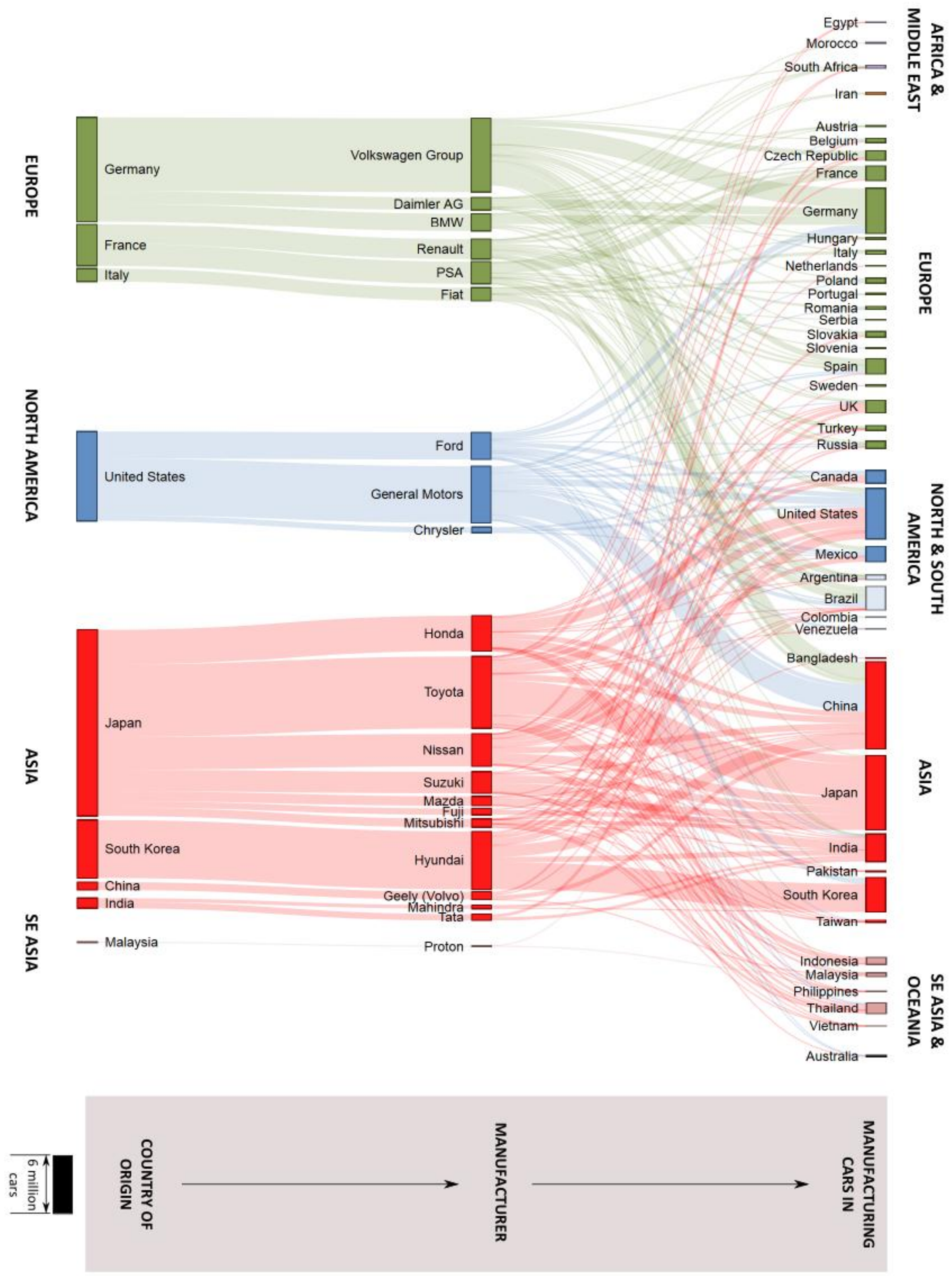


Figure 27: Manufacturing activity of multi-national car manufacturers (data derived from OICA)

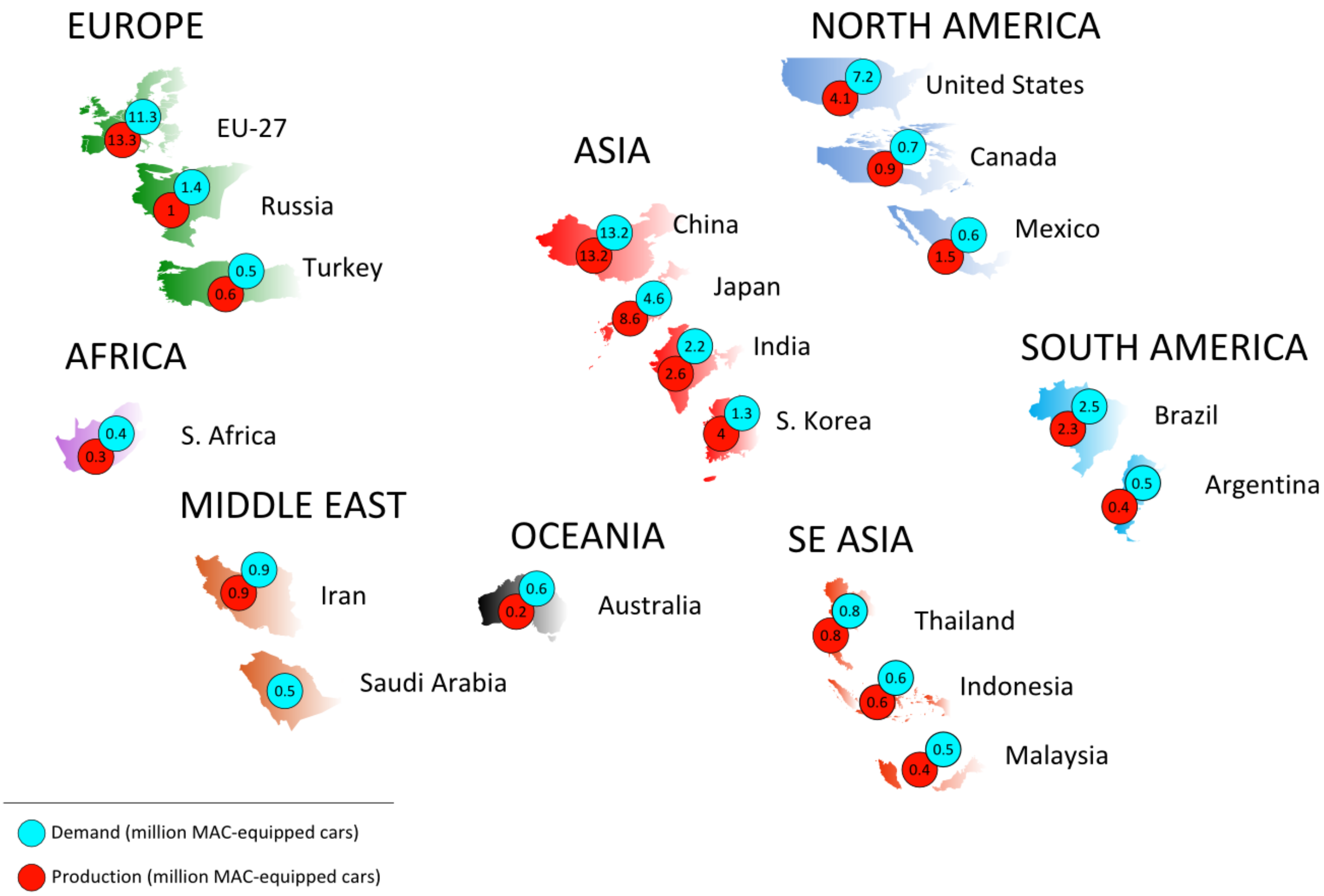


Figure 28: Estimate of world market for MAC-equipped cars in 2012. Countries with surplus production numbers over demand values are considered major car exporting countries

5.4.4 Future demand

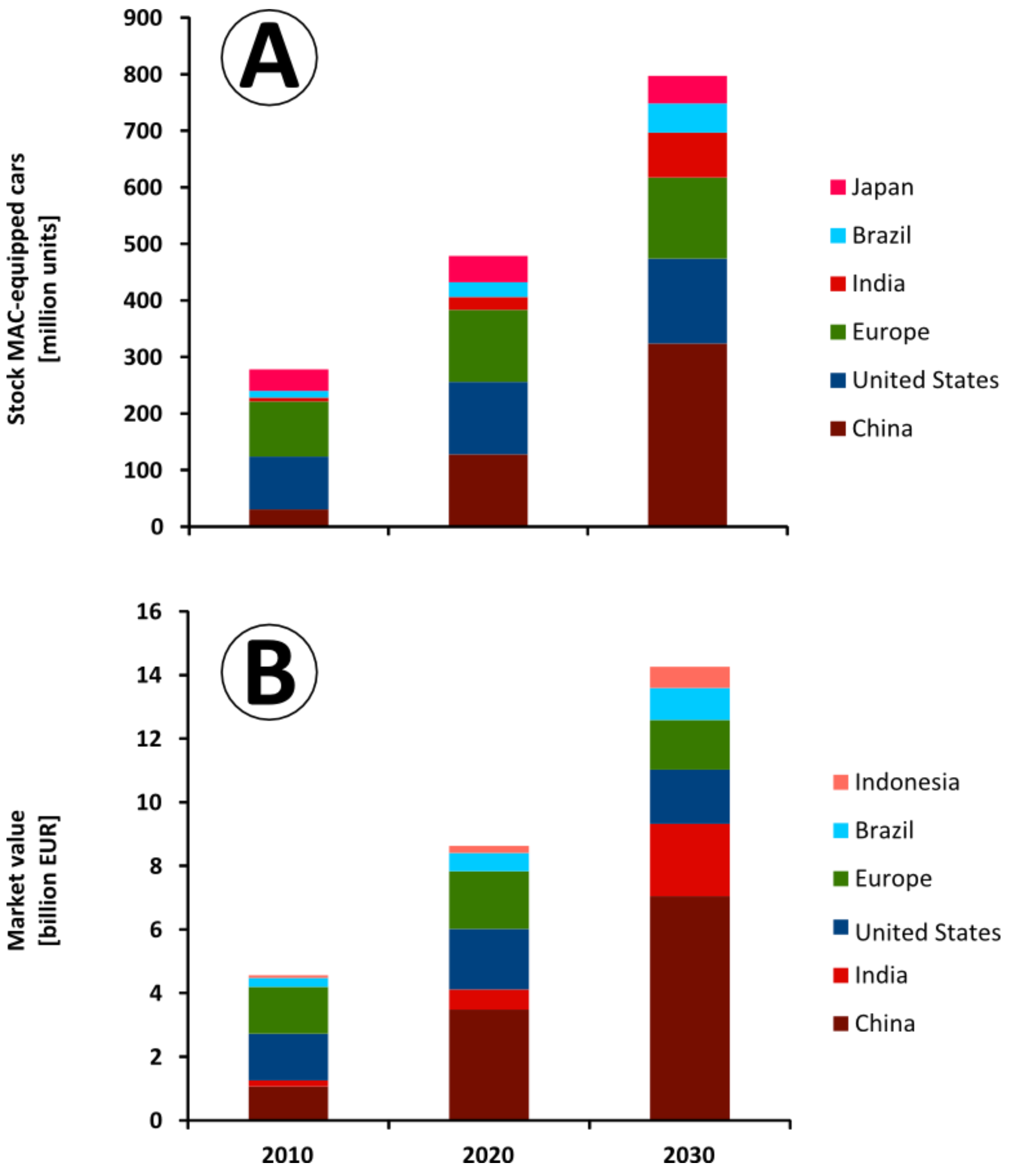


Figure 29: Modelled future stock of MAC-equipped cars for 2010, 2020, 2030 (A) and estimated market value (B) for the top-6 countries

The stock of AC equipped cars in the top 6 countries and regions is projected to increase, with similar growth rates for the different decades (Figure 29A). Most AC equipped cars are currently found in the US and Europe followed by China. However, this picture will change dramatically in future; China will become the dominant player by 2030 (Figure 29A). In Europe and the US, a saturation point will be reached before 2030. This estimated demand pattern follows the ageing and later decreasing population trends which consequently will affect sales in these countries. The current stock of the top 6 countries and regions amounts to nearly 300 million units in 2010 and ca. 800 million units by 2030.

The market generally follows the shares and trends of the stock, except for India. India has less AC equipped cars than the US and Europe, today and in future, however the growth rates are exceptionally high. This explains the second largest market after China with a market worth 2.3 billion Euro 2030. China will have an estimated market of around 7 billion Euro in 2030. The market value of the plotted top-6 (Figure 29B) amounts to about 66% of the global market in 2030.

In contrast to the strong market increase of emerging economies such as China and India, reduced markets are expected in future for Europe. This is primarily caused by the predicted population decline in Germany and the expected stagnation of population in Italy. This highlights the necessity of considering various parameters besides GDP when predicting future stock and markets.

Even though the stock of MAC-equipped cars now and projected in the future is higher in Japan than in Indonesia, the market value in Indonesia is predicted to be higher in 2030. There will be more people buying MAC-equipped cars than in Japan, where the market is relatively saturated.

5.4.5 Future emissions

Different emission pathways are projected for the top 6 countries (Figure 30A). While the US and Europe show a slight increase of emissions, a stagnation is projected from 2025 onwards at a level of 165 Mt CO_2eq. In contrast, high increase of emissions is expected for growing economies such as China and India. While China's emissions will exceed those of the US and Europe between 2015 and 2020 to finally reach levels of more than 500 Mt CO_2eq, India reaches emission levels similar to those of the US and Europe by 2030 (165 Mt CO_2eq).
Again, with the phase-in of green technology based on natural refrigerants, the emissions can significantly be reduced (Figure 30B)[73]. Highest emission savings can be achieved in China with more than 250 Mt CO_2eq annually by 2030. Followed by a large margin are the US, Europe and India, with an annual mitigation potential below 50 Mt CO_2eq. Interestingly, Indonesia is among the top-6 with highest emission reduction potential. The top-6 countries make up 66% of the global mitigation potential in this specific subsector.

[73] A full description of the mitigation scenario can be found in module 5 of the technical handbook "NAMAs in the refrigeration, air conditioning and foam sectors" (Proklima, 2013).

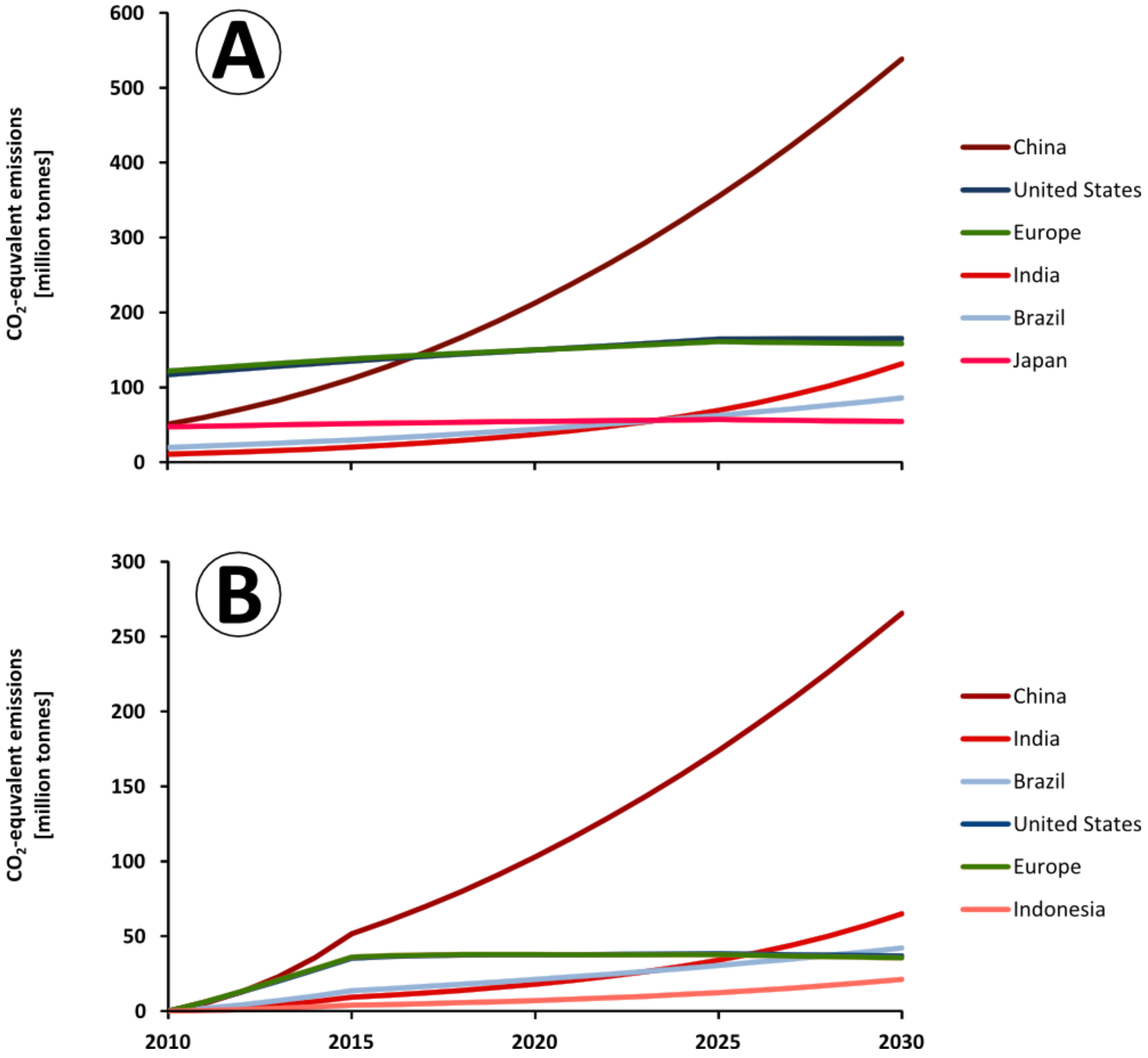


Figure 30: Projected total (direct and indirect) emissions from AC equipped cars for the top-6 countries as calculated by a vintage bottom-up stock model (A). Key determining factors are stock and sales figures. The upper graph (A) shows the BAU scenario, while the bottom graph (B) shows the mitigation potential.

5.5 Conclusion

Contrary to the other subsectors, the MAC subsector is usually uniform with one refrigerant solution for all MAC units. At the moment the subsector is facing change as the European MAC directive bans the use of HFC-134a, which is the current global standard. Whilst most car manufacturers have opted to use u-HFC-1234yf in the future, three German manufacturers have decided to switch to CO_2 because of safety concerns of u-HFC-1234yf.

There are four demand centres globally, the US (with similar structures in Canada and Mexico), the EU, Japan and China. Production usually follows demand and the traditional markets US, Japan and Europe are dominated by their established patterns where mostly EU MAC suppliers are linked to EU automobile manufactures etc. Production has often been moved to China with China now being the number one demand country.

A global change to CO_2 could be possible by transforming some demand centres. As it is preferable and cheaper for car manufacturers to have one solution for all their cars the other demand centres would follow. It will be interesting to see if other regions will follow Europe in the move towards low GWP refrigerants in the MAC subsector. China will likely play a decisive factor in this regard with being the leading market for car and MAC manufacturing. Most European players present in China are likely seeking synergies with their technological developments in Europe. Legislation about refrigerants in countries with less demand would have little impact on the global market.

At the moment there are hardly any energy-efficiency standards for MACs and therefore no incentives for MAC producers to improve the energy-efficiency. Obligatory fuel standards for passenger cars that include MAC use or MEPS for MAC should be introduced. Again, because of the global nature of the MAC subsector, fuel standards or MEPS in a few key countries could help improve energy-efficiency in the whole subsector and have a significant global impact.

Manufacturers and OEM suppliers can get involved in the development of standards for CO_2 MAC systems, which would make an introduction in other countries easier and allow early movers competitive advantages. There is an opportunity for Chinese suppliers to establish strategic coalitions with German OEMs to develop innovative CO_2 MAC solutions, initially, for the Chinese market. NGOs can promote the introduction of MAC in fuel standards and highlight the problems of accumulating TFA levels due to u-HFCs.

6 Chillers

6.1 Subsector characterisation

6.1.1 Overview

In chillers water is cooled by the evaporator. Cooled water is then distributed over longer distances and used to cool whole buildings (air-conditioning chillers) or industrial processes such as plastics and rubber manufacturing and food processing (process chillers) (biois, 2011).

There are few technical differences between AC chillers and process chillers. The cold water from AC chillers usually has higher temperatures than in process chillers where medium and low temperatures are more common (bios, 2011). Even though every chiller, by definition, cools water; there are water-cooled (WC) and air-cooled (AirC) chillers. This refers to the method used to remove heat from the condenser. Chillers vary in their cooling capacity, which can range from as little as 1.75 kW for AirC chillers and up to several MW for WC chillers. Different capacity chillers are equipped with different compressors. Typically process chillers have a lower COP because these chillers need to generate lower temperatures.

Efficiencies are given in COP, EER, SEER or integrated part load volume (IPLV, see box "Terms 4: Energy efficiency terms" in chapter 3). The latter also takes different part load efficiencies into account. The main conventional HFC or HCFC refrigerants used are HFC-134a, R410A, R407C and HCFC-22. HCFC-22 is still in use in developing countries but new appliances are also increasingly moving to the other refrigerants named here. The natural refrigerants propane (HC-290), propene (HC-1270), ammonia (R717) and CO_2 (R744) are regularly used in commercially available chillers.

The focus here will be on AC chillers (about 2/3 of all chillers [Clodic et al., 2010]), because of application homogeneity. However, technical trends and emission reduction potentials are similar for process chillers.

End-users of AC chillers are predominantly office buildings and the retail sector. The health sector (e.g. hospitals) and the leisure and hotel sector play a secondary role.

As an alternative to chillers, Variable Refrigerant Flow systems (VRF) systems have been marketed as alternatives (Amarnath and Blatt, 2008). These have developed from multi-split air conditioners and combine one outdoor condensing unit with several (up to 60) indoor units. A variable speed compressor regulates the refrigerant flow so that each indoor unit can be adjusted individually (Aynur, 2010). In most systems, each indoor unit is connected with refrigerant piping. This makes it a difficult application for natural refrigerants as VRF requires high amounts of refrigerant, with a good quantity in occupied spaces (Aynur, 2010). CO_2 is an option that is being considered in regards to new restrictions on synthetic refrigerants from the European F-Gas regulations, but is generally not efficient enough (cci, 2013).However, there are recent developments where the refrigerant is kept completely outside, similarly to chillers (cci, 2013[74]). VRFs are generally more expensive than chillers but can be more energy efficient (Aynur, 2010).

[74] see also www.acr-heat-pumps-today.co.uk/Air_Conditioning_and_Refrigeration-ch1/News/

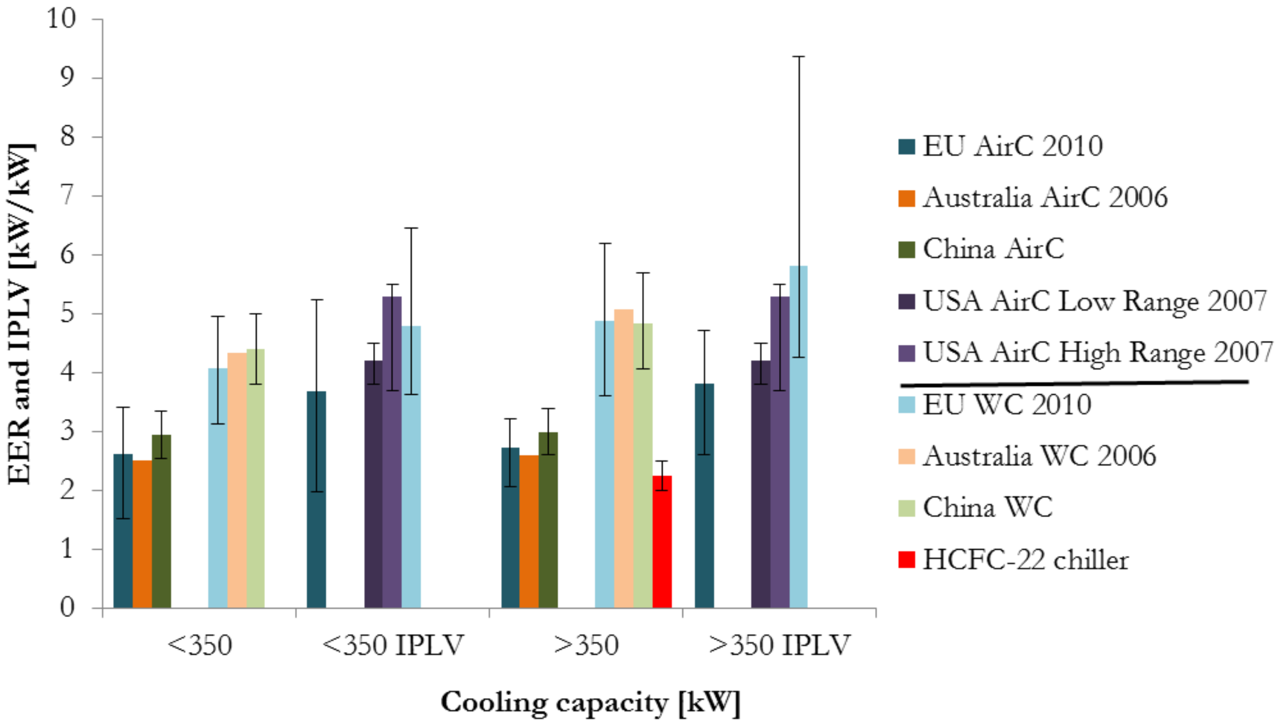
6.1.2 Energy efficiency trends

Chillers with lower capacities generally have lower efficiencies but the range of efficiencies is relatively uniform below and above 350 kW (Armines, 2012). Lower capacity chillers usually have scroll compressors whilst screw compressors are used for medium capacity and centrifugal compressors for high capacity chillers, which also have the highest efficiencies.

IPLV or SEER ratings are always higher than fixed-point EER ratings because they also consider the efficiency at lower temperatures, which is always higher than the efficiency at high temperatures. WC chillers have higher capacities and are usually more efficient than AirC chillers. Water has a higher heat transfer capacity, so that less water is needed than air for the same amount of heat rejection. Water is also normally cooled in a cooling tower. There are some high efficiency range AirC products that are comparable to WC chillers in their efficiency (Naguib, 2011).

There is relatively little data published on chiller efficiency trends or efficiency in different countries. The reason for this could be the inhomogeneity of chiller products that are not easily categorised. Data is available from the EU, the US, Australia and China[75]. Differences between countries are lower than the range of EER or IPLV within one country in one category, which can be very high. The highest efficiency in part-load efficiency lies at 9.4, which is reached by an oil-free centrifugal WC chiller.

This is made possible by magnetic bearings reducing friction losses, the lack of oil interfering with efficiency, extremely high efficiencies in the 25 to 60% load operating range and very good control of variable load (McQuay, DanfossTurbocor). In the US, more than 40% of centrifugal chillers use this technology already[76]. Other significant markets are Europe and Australia and growth is expected in China, India, Russia, and Brazil.



[75]Chinese chiller efficiencies are label grades from 2004 where grade 3 is taken as the average and grade 1 and 5 make up the maximum and minimum respectively. EER from the EU in 2010 are approximately represented by EUROVENT grades from 2005, with the average corresponding to the median grade.

[76] http://mnashrae.org/downloads/Presentations/magnetic_bearing_oil_free_technology_mn_ashrae.pdf

Figure 31: Average EER and IPLV for different countries

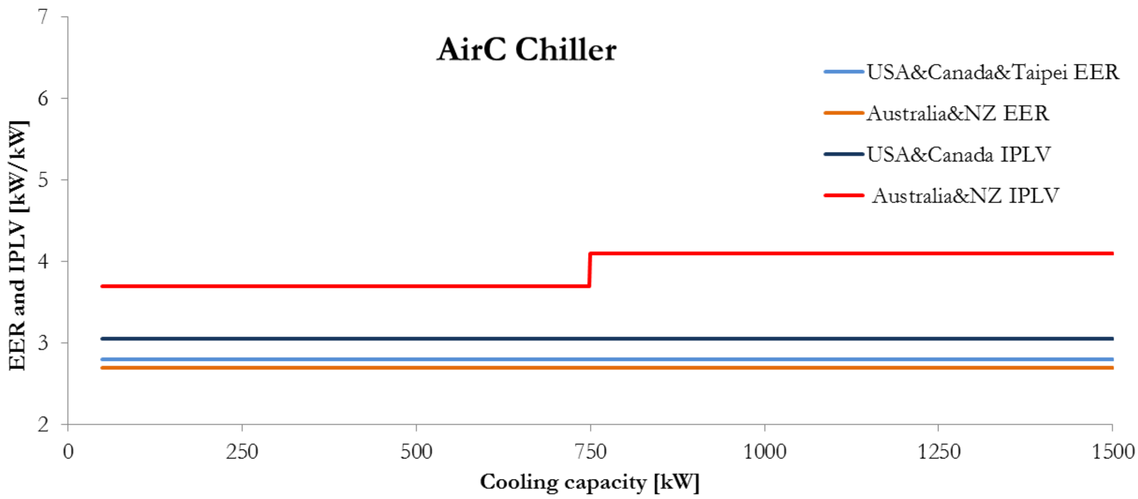
6.2 International and national regulations

Few countries have introduced MEPS regarding chillers and only AC chillers are considered
Figure 32). Because of the importance of part load operation, MEPS are sometimes also given for IPLV values (Australia &New Zealand, USA & Canada). The wide range of chillers is taken into account by different specifications in the MEPS.

There are different requirements for AirC and WC chillers, the range of cooling capacities and different compressors. In Australia and the USA, there are higher IPLV requirements for chillers that are primarily run during part-load operation and they need to be equipped with more accurate part-load controls (data not shown here). There are few differences in the EER and IPLV of different countries, but MEPS in Australia and New Zealand, which were introduced later, have more stringent requirements. There are labelling programmes for AC chillers in the EU and China with the Chinese grades requiring slightly higher efficiency.

A difficulty in comparing EER or IPLV values from different countries is that there is no international test standard yet.

The imminent phase-out of HCFCs in developing countries and increasing restrictions on the use of HFCs will lead to significant changes in the refrigerant use in chillers.



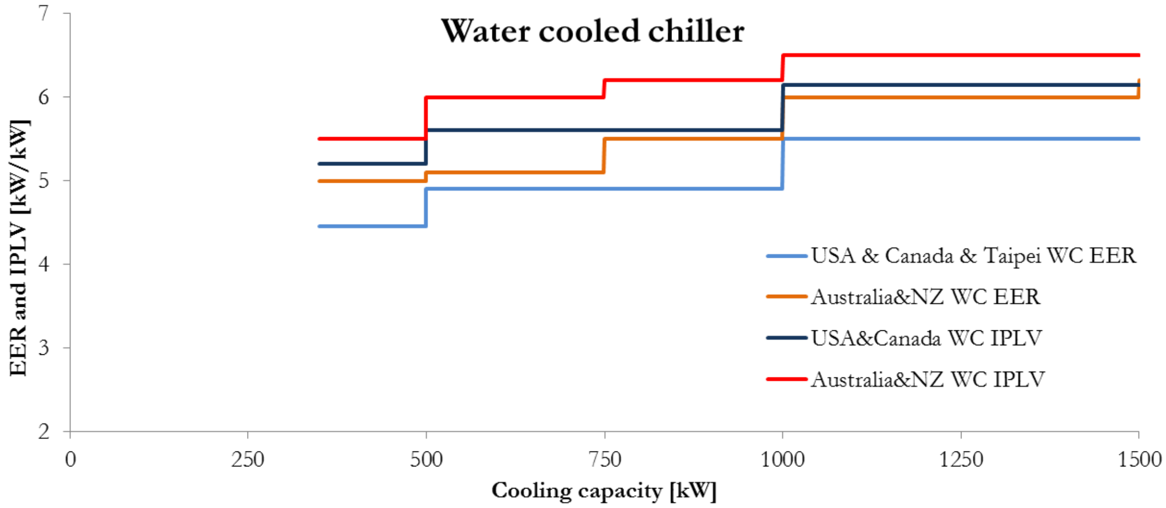


Figure 32: MEPS EER and IPLV requirements for AirC (A) and WC (B) chillers.

6.2.1 Alternative technologies/refrigerants

Propane (HC-290) and propene (HC-1270), ammonia (R717) and CO_2 (R744) are already used in chillers, especially in process chillers.

- The use of ammonia is a more cost-efficient solution for chillers with high cooling capacity (>500-700kW) whereas HCs dominate at smaller capacities. Because of the high amount of refrigerant and their respective flammability and toxicity, safety measures have to be taken. This usually includes installation of the majority of the refrigerant cycle outside of buildings or in a special machinery room. The water that is then transported to cool occupied spaces poses no risk in itself.
- The high amount of refrigerant, reaching from several kg to several tonnes, means that leak reduction can significantly reduce direct emissions. Emissions can occur during servicing even if the piping is assumed hermetically sealed and reach 5 to 10% a year (Clodic et al., 2010). Leakage rates in developing countries are considerably higher and in the range of 14 and 30%, with an average of 20% (UNEP, 2013).
- End-of-life recovery ranges from 10 to 80% (Armines, 2012), however this is not common practice in developing countries, where the majority of refrigerant is vented into the atmosphere.

6.2.2 Indirect emissions

Energy efficiency can be improved by replacing some components with high efficiency parts. The highest gains can be reached by optimising the heat exchanger and using an inverter compressor to allow for part-load operation. As most chillers only run at full-load for a short period of the year and are generally more efficient when they do not, including an inverter or another means of controlling the capacity (e.g. installing two compressors and being able to switch one off if it is not needed) lead to higher overall energy efficiency. HCs have particular advantages in high ambient environments where energy efficiency improvements in comparison to HCFC-22 chillers of about 15% can be achieved[77]. Chillers using HC-290 as refrigerants are up to 10% more efficient (Pedersen, 2012) due to the thermodynamic properties of HCs.

Challenges: CO_2 systems for AC chillers are available, but are far less efficient than hydrocarbon or ammonia chiller[78].

[77] D.Colbourne: Overview of the use of Hydrocarbon Refrigerants in chillers, UNEP chiller conference, Cairo, September 2010.
[78] Advansor, personal communication at Atmosphere 2013, 15/10/2013, Brussels.

Table 12: Energy efficiency measures for chillers

	Measure	Improvement COP
Cycle improvements	Inverter/variable Speed (flow) Compressor Heat exchanger	36% max
Parasitic losses		
Cycle modifications	HC	10 % (Pedersen, 2012)
Change in use	Part-load controls Right positioning and maintenance	30% (biois,2011)

6.2.3 Reducing cooling needs

For AC chillers, the same considerations as for UAC apply. Even more cooling needs can be reduced by planning and designing office buildings and hospitals with the minimisation of the cooling load in mind. It is also important to choose the chiller according to the needed capacity. The location where a chiller is installed and general considerations about its operation and maintenance can lead to very high savings in electricity consumption. This includes selecting a place that is not close to other heat sources, choosing the optimum water temperature, managing and cleaning pumps and filters and fine-tuning for partial-load operation (biois, 2011).

6.2.4 CO_2 emissions over lifetime

Figure 33 shows the lifetime CO_2 emissions for AC chiller in a comparison of the BAU to several mitigation scenarios. AC chillers have very high energy demand so that direct emissions only contribute about 3% to total emissions in industrialised countries and 4.5% in developing countries. Direct emissions are about twice as high in developing countries because of higher leakage rates and little refrigerant collection at the disposal of units. Significant total emission reductions can therefore only be reached by improving energy efficiency or decarbonising electricity generation. For the global reduction of direct refrigerant emissions, chillers play an important role because of their high refrigerant content and relatively high leakage rates and low recovery efficiency. Direct emissions of AC chillers are 20 times higher than those from UACs. A combination of energy efficiency measures and natural refrigerants can reduce total emissions by 40% in industrialised countries and up to 60% in developing countries.

The ecodesign study on AC chillers sees a significant reduction potential by switching to an energy efficient natural refrigerant model (Armines, 2012). Process chillers usually operate on lower temperatures and therefore have an even higher energy input resulting in higher indirect emissions than AC chillers. In order to reduce total emissions, it is therefore even more important to increase the energy efficiency of process chillers (biois, 2011).

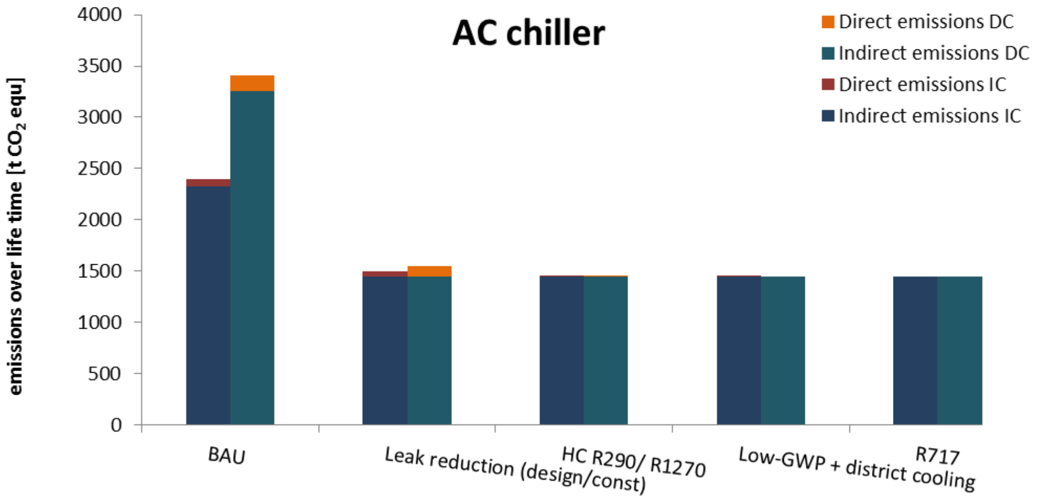


Figure 33: CO_2 emissions over lifetime in AC chillers in developing countries (DC) and industrialised countries (IC) . An average value has been applied for IC and DC as there are significant differences within those country groups.

6.3 Production and demand

6.3.1 Overview

Chillers are used for cooling in industrial, commercial as well as residential applications and therefore come with a whole range of different cooling capacities. The cooling capacity of chillers usually depends on the compressor type, but there is some overlapping between them. Chillers can be categorised intro three classes according to the type of compressor they use:

- positive-displacement (reciprocating, scroll, screw) and
- centrifugal
- absorption chillers

The following section will focus on the market for positive-displacement and centrifugal chillers. Among the three chiller classes, absorption chillers have the lowest market share[79]. Absorption chillers do not use electrical compressors but heat as energy source. They use natural refrigerants, have extremely low COPs and are normally only used when waste heat is available. They represent an extremely small fraction of the market and as such will not be discussed further.

The smallest power classes of chillers are chillers with reciprocating and scroll compressors, the latter with a typical cooling capacity of up to 280 kW. Reciprocating chillers are now rarely used for air conditioning but mostly for refrigeration[80]. Modular chillers with scroll compressors maintain a stable market share and because of their cost-effectiveness they may become an alternative to screw chillers in some applications[81].

Screw chillers occupy medium cooling capacity ranges (from around 18 to 1400 kW). In the upper cooling power classes modular set-ups compete with centrifugal chillers (from around 1050 kW) and are becoming an interesting option since they are cheaper. . Centrifugal chillers are used for the highest cooling capacity classes.

[79] http://www.prweb.com/releases/absorption_chillers/renewable_energy/prweb8512514.htm
[80] http://www.ejarn.com/news.asp?ID=27026
[81] Chiller sales follow trends in the Economic environment. BSRIA Press Release 46/12. China Electric Appliance Manufacturer. (2011). China Air Conditioning Industry

6.3.2 Demand

The demand for chillers is highly influenced by the general economic development. The key drivers of the chiller market are the construction activity besides the refurbishment or replacement of existing chillers. As there was limited access to data on unit sales of chillers, the focus of this section is on the value of the chiller market, which is a common way to describe this market. Unit prices differ considerably depending on the chiller's cooling capacity an type.

The total value of the global positive-displacement and centrifugal chiller market was around USD 7.4 billion in 2012[82], roughly a tenth of the global UAC market. The global market value distribution of 2012 is illustrated in Figure 34. The UAC market (see chapter 4.3) is growing faster than the chiller market. Especially as VRF systems are a competitive alternative to chillers with regard to ease of installation, advantages in maintenance and commissioning, individual zone air-conditioning control and increased energy efficiency. The decision for using VRF instead of a chiller for central air conditioning however is project-dependent and prone to certain initial costs which need to be factored in[83].

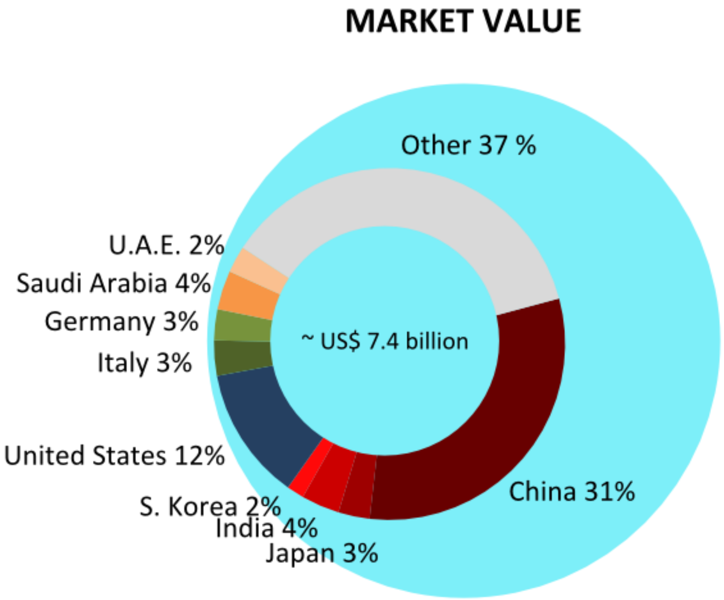


Figure 34: World positive-displacement and centrifugal chiller market in 2012 by market value

[82] JARN's Chiller Special 2013

[83] https://www.ashrae.org/File%20Library/docLib/Journal%20Documents/April%202007%27/20070327_goetzler.pdf

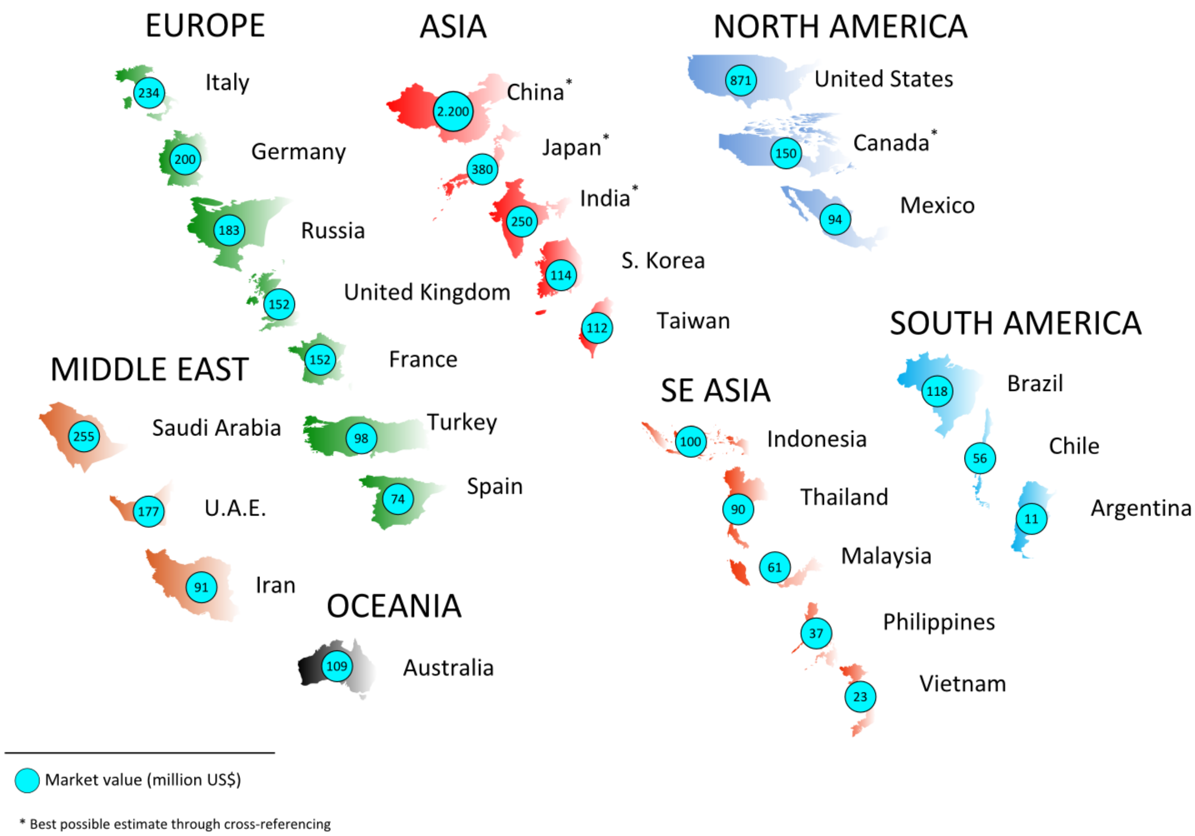


Figure 35: World positive-displacement and centrifugal chiller market in terms of market value. Note: The data presented here is drawn from various sources and reflects the best available information.

With the growth of developing and emerging economies, the chiller market is continuously expanding. The distribution of chiller market value by region among key countries is depicted in

Figure *35*.

More than half of the world's market value is located in the Asian and SE Asian economies. China is the largest chiller market and also the largest market for process chillers. Japan is the second largest market in Asia and is turning into a refurbishment market. Indonesia is the largest market in SE Asia and continuing infrastructure development. Expanding construction of commercial and public buildings will lead to growing demand. Thailand sees growth in reconstruction after the flooding in 2011 and demand from commercial and industrial operations is picking up again.

Other major markets are the US, the Middle East, and Europe. The US is the second largest AC chiller market globally. Its manufacturers have expertise in centrifugal chillers, which is of great interest in Middle Eastern countries and Saudi Arabia where the demand for district cooling is picking up. In Europe chiller sales are falling due to lacking economic recovery. In markets such as Germany, France, Italy, and Spain, the majority of units sold are scroll chillers with capacities below 100kW.

In Europe, the relative global share of chillers is higher than that of UAC units. This is due to the fact that AC for domestic cooling purposes are used to a much lower extent in Europe than in Asia. In comparison, commercial air conditioning by chillers is more widely spread.

6.3.3 Production

Figure 36 presents the countries of key chiller markets with the main national chiller producing companies. Figure 37 shows the activity of manufacturers on the international stage by the locations of their production facilities. Manufacturing of chillers is not as dominated by companies of Asian countries as that of UAC units. Companies come from a range of countries and have also distributed their production sites in diverse countries.

As shown in Figure 37 chiller production and sales seems to be directed from regional hubs in specific countries from which distribution may be logistically more effective – other than the highly concentrated mass production of UACs (chapter 4.3). Many chillers are still made according to the specifications of the order or customised to the local requirements. Especially in Europe (e.g. Italy), there are many local producers of chillers.

CHINA	AUX, Bright, Broad, Changhong, Dun'An, Gree, Haier, Midea, Shuangling, TCL
JAPAN	Ebara, Daikin, Hitachi, MHI
INDIA	Blue Star, Kirloskar, Voltas
TAIWAN	KuenLing
MALAYSIA	O.Y.L. (Daikin)
ITALY	Aermec, Blue Box, Climaveneta, Clivet, Geoclima, RC Group, Rhoss
GERMANY	GEA Grasso
FRANCE	Airwell, CIAT
UNITED KINGDOM	Airdale
SAUDI ARABIA	Petra, SKM, Zamil
IRAN	Saran, Saravel
BRAZIL	Refrisat
UNITED STATES	Carrier, McQuay (Daikin), Dunham-Bush, Mammoth, Trane, York

Figure 36: Manufacturers in key chiller-producing countries. Note: Some may act on multi-national level (see next figure).

US chiller manufacturers, such as Carrier, York and Trane attempt to diversify their production sites around the world in order to maintain market dominance. Even though US manufacturers increasingly transfer the mass-production to China and other countries, production of core components and high-performance/-efficiency chillers remains in the US. US chiller manufacturers are well positioned in Asia and SE Asia and dominate the local markets. Chiller products manufactured in the US have also a very high popularity in the Middle East.

However, Chinese manufacturers, such as Gree, Haier, Midea and Dun'An are gaining global market share. In 2011, 12% of total sales of Chinese producers were exported[84]. Chinese companies so far mainly export to SE Asia and the Middle East.

Japanese manufacturers seem to follow the strategy of US chiller companies, which is to manufacture the bulk in their Chinese factories, but to keep the production of high-performance chillers and parts in Japan. There is strong competition for Japanese chillers from US chillers made in China.

Factories in Europe mainly provide small and medium-sized chillers with capacities up to 350 kW. Most of the European chiller production takes place in Italy. Around 75% of these are small air-cooled chillers with capacities lower than 100 kW and a large proportion is going into exports. Both European and Chinese manufacturers compete for market share in the Middle East.

[84] China Electric Appliance Manufacturer, 2011

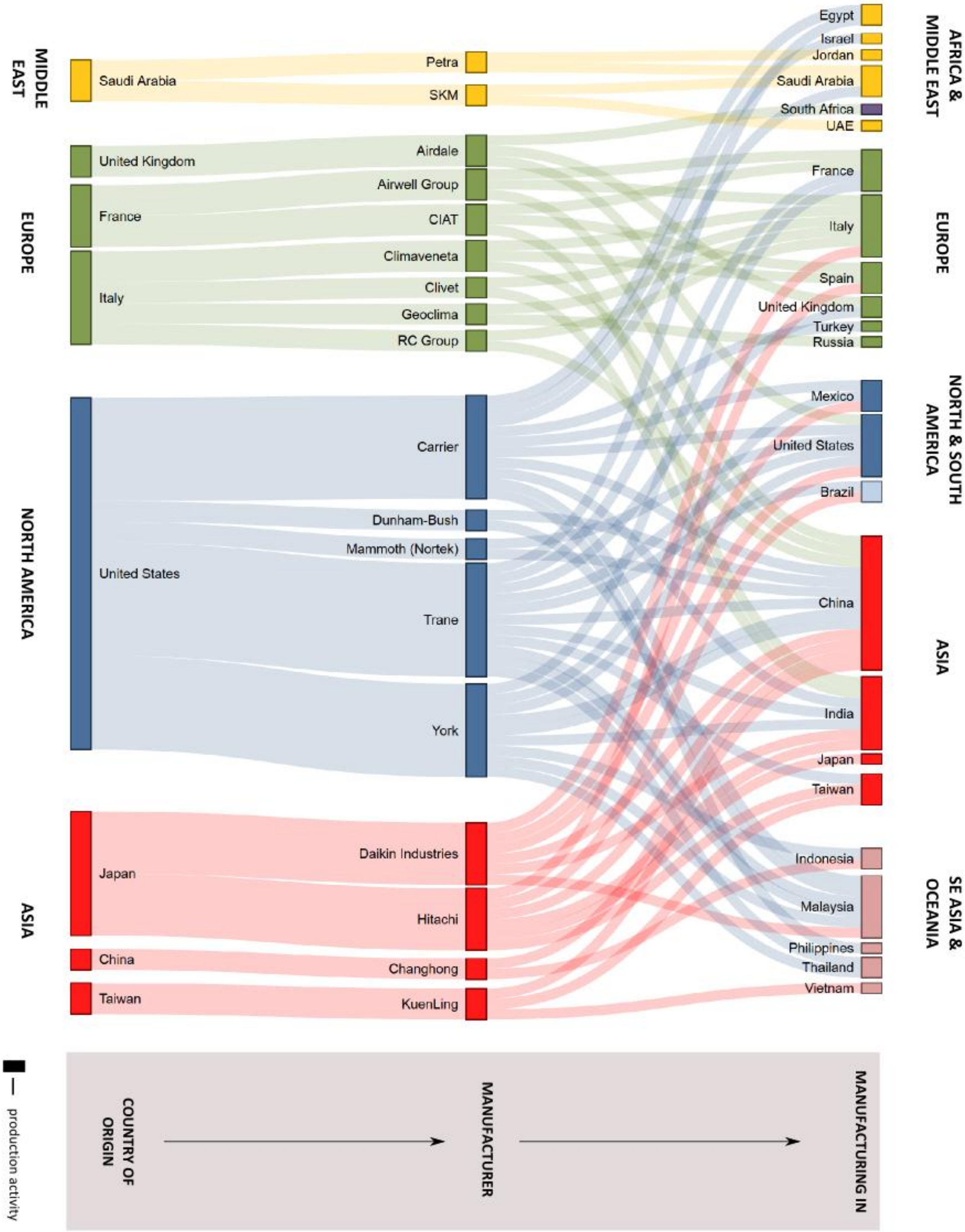


Figure 37: Production bases of major positive-displacement and centrifugal chiller manufacturers Note: The scale has no base unit.

VRF systems

Under certain conditions, which depend on a building's application and planning, VRF systems can be a suitable alternative to small and medium-sized chiller installations. The VRF market in various countries is rapidly expanding and since being comparable to the value of the chiller market (USD 7.4 billion) it will be marginally addressed here. VRFs were initially introduced through Japanese manufacturers. Growth in VRF sales in 2012 could be observed in many countries, such as China (8%) and India (5%). In Brazil growth was as high as 50% in the first quarter of 2013 and this seems to be related to the World Cup in 2014 and the Olympic Games in 2016[85]. The highest expected growth rates between 2012 and 2015 are 31% in the USA, 19% in Russia, 16% in Turkey, 14% in India and 10% in China[86].

The largest market, again, is China, with about half of the total of 850,000 units sold in 2012, followed by Japan and South Korea. Mini-VRF systems have become very popular China and are increasingly used both residentially and commercially. Because of the recent housing construction boom in China and the subsequent installation of mini-VRFs, they now account for 70% of residential central air-conditioning.

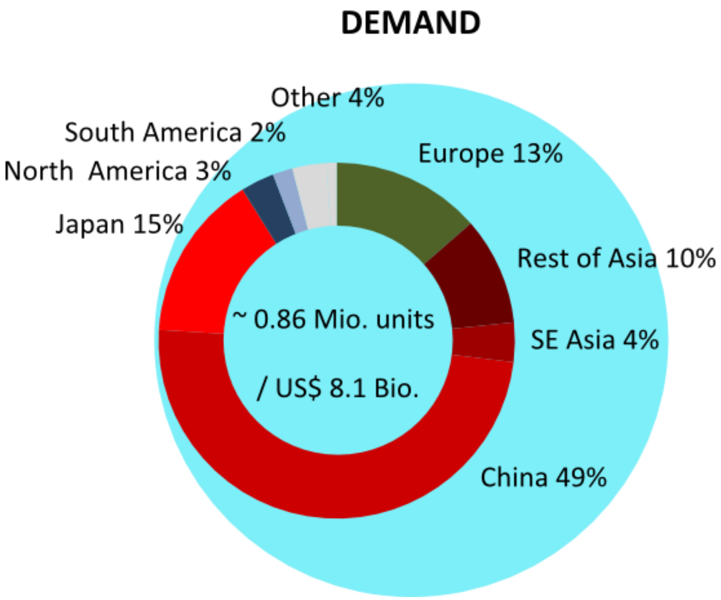


Figure 38: Estimate of global share of VRF systems by market size in units

6.4 Conclusion

The chiller market is relatively small compared to the UAC subsector, but demand is also rising and as more and more building projects include central air conditioning in the planning stage instead of having occupants buy their own UAC at a later stage, it will grow considerably in the future.

Whilst China is also the single most important country when it comes to demand, the production of chillers is much more diverse than in the UAC subsector. There are still big international brands with global presence but production is often local and this leaves room for smaller companies with innovative highly energy efficient green cooling technologies using natural refrigerants. Chinese brands are emerging in the global market but are far from dominating. Chinese manufacturers could gain market shares both domestically and abroad with Green Chiller technologies.

While MEPS are implemented in some developed countries, they play a far lesser role than in UAC for improving energy efficiency. Because chillers are often made for a specific purpose it is necessary to set a whole range of MEPS, which are difficult to keep track of. Building standards and guidelines for planning energy efficient AC chillers

85 http://www.ejarn.com/news.asp?ID=27161
86 Holley AM, Global Trends in Air Conditioning, BSRIA AHR, 29th, 2013

are more important. Public procurement can also help promote environmentally-friendly chiller technologies, by making it a requirement for government buildings and government-funded projects. Banks can also support green cooling targets by only financing projects where guidelines about environmentally-friendly chillers are met.

Chillers with natural refrigerants contain high amounts of HCs or ammonia and can pose a risk if they are not installed correctly. International standards on the safe installation of chillers are crucial in promoting environmentally-friendly chillers and NGOs can play a role in driving standard development. International standards are especially important for developing countries without their own standardisation processes.

High leakage rates and energy consumption mean that energy efficient chillers using natural refrigerants can reduce total emissions by 40-60%.

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8 Annex

8.1 List of abbreviations

AAR – Indian Association of Ammonia Refrigeration

AC – Air conditioner

ABRAVA – Associação Brasileira de Refrigeração, Ar Condicionado, Ventilação e Aquecimento

ADB - Asian Development Bank

AFD – Agence Française de Développement

AfDB - African Development Bank

AirC – air-cooled

ASERCOM - the Association of European Refrigeration Compressor Manufacturers

BAU – business as usual scenario

BEE - Bureau of Energy Efficiency

BMU – German Federal Ministry for Environment, Nature Conservation and Nuclear Safety

BMZ – German Federal Ministry for Economic Cooperation and Development

BSRIA – Building Services Research and Information Association

CCAC – Climate and Clean Air Coalition

CEN – Comité Européen de Normalisation

CENELEC – Comité Européen de Normalisation Electrotechnique

CFC – chlorofluorocarbons

CGF – Consumer Goods Forum

CO_2 – carbon dioxide

COP – Conference of the Parties

COP – coefficient of performance

CPI - Climate Policy Initiative

CSR – Corporate Social Responsibility

CTCN – Climate Technology Centre and Network

DC – developing countries

DTI – Danish Technological Institute

EAC - East African Community

EE – Energy Efficiency

EEB – European Environmental Bureau

EER – Energy Efficiency Ratio

EIA – Environmental Investigation Agency

EP – Equator Principles

EPEE – European Partnership for Energy and the Environment

EU – European Union

GEF - Global Environment Facility

GCI – Green Cooling Initiative

GDP – gross domestic product

GHG – greenhouse gas

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

GM – General Motors

GPP – green public procurement

GWP – global warming potential

HC – hydrocarbon

HCFC – hydrochlorofluorocarbons

HF – Hydrogen fluoride

HFC – hydrofluorocarbons

HCl - Hydrogen chloride

HFO – hydrofluoroolefin

HPMPs – Hydrochlorofluorocarbon-Phase-out-Management-Plans

IADB - Inter American Development Bank

IAA – Internationale Automobil-Ausstellung (Frankfurt Motor Show)

IC – industrialised countries

ICI – International Climate Initiative (German: IKI – Internationale Klimaschutzinitiative)

IEA – International Energy Agency

IEC – International Electrotechnical Commission

IGSD - Institute for Governance and Sustainable Development

IIAR – International Institute of Ammonia Refrigeration

IIR – International Institute for Refrigeration

IFC – International Finance Corporation

ILK – German Institut für Luft- und Kältetechnik

IPLV – Integrated Part Load Value

ISO – International Standardisation Organisation

JARN – Japan Air Conditioning, Heating & Refrigeration News

JRAIRA - Japan Refrigeration and Air Conditioning Industry Association

JRC – Joint Research Center of the European Commission

LCCP – life cycle climate performance

MAC – mobile air conditioning

MEPS – minimum energy performance standards

MLF – multilateral fund

NAMA – Nationally Appropriate Mitigation Action

NGO – non-governmental organisation

NH_3 – ammonia

ODP – ozone depletion potential

ODS – ozone depleting substances

OECD – Organisation for Economic Co-operation and Development

OEM – original equipment manufacturers

OICA – Organisation Internationale des Constructeurs d'Automobiles

RAC – refrigeration and air conditioning

R&D – research and development

SARDA - Southern African Refrigerated Distribution Association

SE Asia – Southeast Asia

SEER – Seasonal Energy Efficiency Ratio

SIS – Swedish Standards Institute

SIDA – Swedish International Development Cooperation Agency

SME – small and medium size enterprises

SNAP - Significant New Alternatives Policy

TFA – trifluoroacetic acid

TEC – Technology Executive Committee

TERI - The Energy and Resources Institute

TEWI – Total equivalent warming impact

UAC – Unitary Air Conditioning

UN – United Nations

UNEP – United Nations Environment Programme

UNDP – United Nations Development Programme

UNFCCC – United Nations Framework Convention on Climate Change

UNIDO – United Nations Industrial Development Organisation

US EPA – US Environmental Protection Agency

VRF – variable refrigerant flow

WBCSD – World Business Council for Sustainable Development

WC – water-cooled

WWF – World Wide Fund for Nature

8.2 Glossary

Annex I/non-annex I countries: The UNFCCC divides parties into different groups according to their commitments. Annex I parties are industrialised countries and some economies in transition, and non-annex I countries are mostly developing countries.

BAU (business as usual) scenario: A business-as-usual scenario serves as a reference scenario to estimate the future potential for emission reductions. It can be a powerful tool to simulate future emissions and demand of fluorinated substances. In different scenarios, mitigation measures can be illustrated by the models for each sector to demonstrate the reduction potential in a quantitative manner.

CFC (chlorofluorocarbons): Halocarbons containing only chlorine, fluorine and carbon atoms; these are both ozone-depleting substances (ODSs) and greenhouse gases. CFCs were the most commonly used of the chemicals controlled by the Montreal Protocol. Since the end of 2009 they have been virtually phased out, with remaining uses limited to medical inhalers in a very small number of countries.

COP (coefficient of performance): A measure of the energy efficiency of a refrigerating system, which is defined as the ratio between the refrigerating capacity and the power consumed by the system and primarily dependant on the working cycle and the temperature levels (evaporating/condensing temperature) as well as on t he properties of the refrigerant, system design and size (the comparable term “EER” or “energy efficiency ratio” is also used).

CSR (Corporate Social Responsibility): A concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis.

EER (Energy Efficiency Ratio): Similar to the COP, but the performance is tested at one defined inside and outside temperature at full cooling capacity. Test conditions are derived from an ISO standard and vary slightly between countries but this does not lead to significantly different results.

GHG (greenhouse gas): The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation within the spectrum of the thermal infrared radiation that is emitted by the Earth's surface, by the atmosphere and by clouds. This property causes the greenhouse effect.

GWP (global warming potential): An index comparing the climate impact of an emission of a greenhouse gas relative to that emitting the same amount of carbon dioxide. GWPs are determined as the ratio of the time integrated radiative forcing arising from a pulse emission of 1 kg of a substance relative to that of 1 kg of carbon dioxide, over a fixed time horizon.

Global Compact: A global initiative that provides a platform for businesses to work with the UN and align their operations with universal principles on human rights, labour, anti-corruption and the environment. NGOs and public research institutions are also participating in the Global Compact.

HC (hydrocarbon): Chemical compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms. Hydrocarbons such as propane and isobutene can be used as refrigerants. They have no ozone-depleting potential and very low global warming potential.

HCFC (hydrochlorofluorocarbons): Halocarbons containing only hydrogen, chlorine, fluorine and carbon atoms. Because HCFCs contain chlorine, they contribute to ozone depletion and they are also greenhouse gases. HCFCs were used as intermediate replacements for CFCs, but they are being phased-out by the Montreal Protocol and will be entirely banned as of 2030.

HFCs (hydrofluorocarbons): Halocarbons containing only carbon, hydrogen and fluorine atoms. Because HFCs contain no chlorine, bromine or iodine, they do not deplete the ozone layer, but like other halocarbons they are potent greenhouse gases. Consumption of HFCs is growing world-wide, due to their function as replacement substances for CFCs and HCFCs.

HPMP (HCFC phase-out management plan): A scheme comprising policy and technical elements that enable a country to phase out the consumption of HCFCs within the schedules prescribed within the relevant amendment to the Montreal Protocol.

Inverter technology: In cooling technology such as air conditioners, inverters enable the control of the compressor speed, so the compressor runs with fewer rotations per minute when less cooling is required, which improves the energy efficiency.

IPLV (Integrated Part Load Value): One value is given that includes the efficiency while operating at various capacities. The efficiency at 100%, 75%, 50% and 25% capacity is measured and it is assumed that the unit runs at these capacities at 1%, 42%, 45% and 12% respectively of its running time (AHRI standard 550/590-2003). The percentages can be varied, given the NPLV (non-standard part load value).

ISO (International Organisation of Standardisations): the world's largest developer and publisher of international standards.

Kyoto Protocol: The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Third Session of the Conference of the Parties (COP) to the UNFCCC in 1997 in Kyoto, Japan. It entered into force on 16 February 2005.It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol agreed to reduce their anthropogenic greenhouse-gas emissions (specifically carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) by at least 5% below 1990 levels in the commitment period 2008 to 2012.

MEPS (Minimum Energy Performance Standards): MEPS are set by some countries to eliminate less efficient products from the market and promote those with highest efficiencies. This is often accompanied with a labelling scheme providing information to customers. MEPS are usually increased stepwise to slowly transform the market to highly efficient products.

MLF (Multilateral Fund): A fund established in 1991 to assist developing (article 5 or short A5) countries in meeting their Montreal Protocol commitments, through financing activities including industrial conversion, technical assistance, training and capacity building.

Montreal Protocol on Substances that Deplete the Ozone Layer: Adopted in Montreal in 1987 and subsequently adjusted and amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999). It controls the consumption and production of chlorine- and bromine-containing chemicals, known as ozone depleting substances (ODSs) that destroy the stratospheric ozone layer. To date 197 signatory states have ratified the Montreal Protocol.

NAMA (Nationally Appropriate Mitigation Action): A set of policies and actions that countries undertake as part of a commitment to reduce greenhouse gas emissions. The term recognises that different countries may take different nationally appropriate action on the basis of equity and in accordance with common but differentiated responsibilities and respective capabilities. It also emphasizes financial assistance from developed countries to developing countries to reduce emissions.

ODP (ozone depletion potential): A relative index indicating the extent to which a chemical product may cause ozone depletion compared with the depletion caused by CFC-11. Specifically, the ODP of an ozone depleting substance (ODS) is defined as the integrated change in total ozone per unit mass emission of that substance relative to the integrated change in total ozone per unit mass emission of CFC-11.

ODS (ozone depleting substances): Substances known to deplete the stratospheric ozone layer. The ODS controlled under the Montreal Protocol and its amendments are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, methyl bromide, carbon tetrachloride, methyl chloroform, hydrobromofluorocarbons and bromochloromethane.

Refrigerant: A fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects it at a higher temperature and a higher pressure of the fluid usually involving changes of the phase of the fluid.

Refrigerating system: A combination of interconnected refrigerant-containing parts constituting one closed circuit in which the refrigerant is circulated for the purpose of extracting and rejecting heat (i.e. heating and cooling).

SEER (Seasonal Energy Efficiency Ratio): Several temperatures are included to account for different cooling needs during the course of the cooling period when a unit is not running at full capacity. In the US the (S)EER is often given in the unit 'British Thermal Units per hour'. A division by the conversion factor of 3.412 makes a comparison with the (S)EER in W/W possible.

Solar Chill Initiative: Solar Chill is an initiative of NGOs, UN and bilateral development organisations, research institutes and industry, which aims at providing affordable and environmentally friendly vaccine coolers and refrigerators for parts of the world that have no or unreliable electricity supplies.

Technology Mechanism: The Technology Mechanism of the UNFCCC targets an accelerated technology transfer across all sectors and countries globally to allow the deployment of the least climate harming technologies. The Technology Executive Committee (TEC), and Climate Technology Centre and Network (CTCN) were formed to implement the technology mechanism.

TEWI (Total equivalent warming impact): This concept takes into account direct and indirect emissions over the lifetime (excluding indirect emissions during production and disposal) and gives one number in CO_2 equivalents.

VRF (variable refrigerant flow): In VRF systems, one outdoor condensing unit is connected to multiple indoor units. These can be individually controlled and therefore run with varying speeds. Compared to other systems that do not allow individual controlling and part-load, VRF systems allow for substantial energy savings.

End of life emissions: End of life emissions refer to the emissions caused by the release of refrigerant when old or decommissioned equipment is disposed of.

8.3 Country list

Countries for which a sophisticated stock modelling approach was applied, using generalised linear and additive models together with various socio-economic parameters:

Afghanistan
Algeria
Angola
Argentina
Australia
Austria
Bangladesh
Belgium
Benin
Bolivia
Botswana
Brazil
Burkina Faso
Cambodia
Cameroon
Canada
Chile
China
Colombia
Costa Rica
Cote d'Ivoire
Cuba
Denmark
Dominican Republic
Ecuador
Egypt, Arab Rep.
El Salvador
Eritrea
Ethiopia
Finland
France
Gabon
Germany
Ghana
Guatemala
Haiti
Honduras
Iceland
India
Indonesia
Iran, Islamic Rep.
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kenya
Kuwait
Lebanon
Libya
Luxembourg
Madagascar
Malawi
Malaysia
Mauritius
Mongolia
Morocco
Mozambique
Myanmar
Namibia
Nepal
Netherlands
New Zealand
Nicaragua
Nigeria
Norway
Oman
Pakistan
Panama
Paraguay
Peru
Philippines
Portugal
Saudi Arabia
Senegal
Singapore
South Africa
Spain
Sri Lanka
Sudan
Sweden
Switzerland
Syrian Arab Republic
Thailand
Uganda
United Arab Emirates
United Kingdom
United States
Uruguay
Venezuela, RB
Vietnam
Yemen, Rep.
Zambia
Zimbabwe

8.4 Tables

8.5 Figures